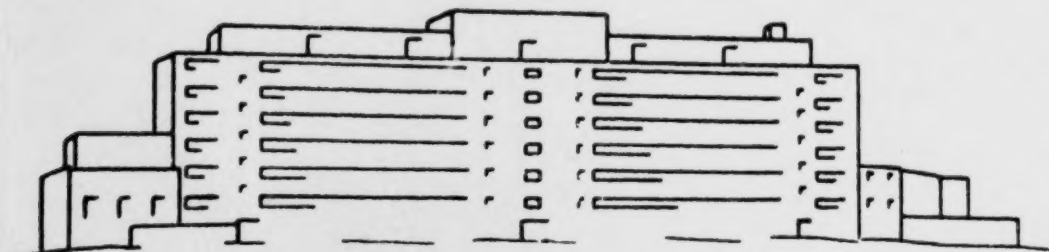


The Robert A. Taft
Sanitary Engineering Center
TECHNICAL REPORT
W60-3

PB 167654



JUN 15 1965

COPY	1	OF	1	22
HARD COPY	\$. 6.00			
MICROFICHE	\$. 1.50			

298p

BIOLOGICAL PROBLEMS IN WATER POLLUTION

Transactions of the 1959 Seminar

U. S. DEPARTMENT OF HEALTH
EDUCATION, AND WELFARE
Public Health Service

BIOLOGICAL PROBLEMS IN WATER POLLUTION

Transactions of the Second Seminar on Biological Problems in Water Pollution, held April 20-24, 1959, at Cincinnati, Ohio under the sponsorship of the Water Supply and Water Pollution Research Program, Robert A. Taft Sanitary Engineering Center.

Compiled by
C. M. TARZWELL, Chief
Aquatic Biology

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service
Bureau of State Services
Division of Water Supply & Pollution Control

Robert A. Taft Sanitary Engineering Center
Cincinnati 26, Ohio

1960

These transactions are dedicated to

WILLIAM C. PURDY

Aquatic Biologist

1871-1954

and

CHESTER T. BUTTERFIELD

Former Research Director who

retired August 31, 1951



William C. Purdy began his career with the U. S. Public Health Service as a "Special Expert in Planktonology" on July 14, 1913. His original tour of duty, which began in the Hygienic Laboratory at Washington, D. C., was to be for three months. It expanded into many years of devoted and outstanding service, during which he pioneered the study of the biology of water pollution. He served at the Stream Pollution Investigation Laboratory in Cincinnati from 1914 to 1918; in Little Rock, Arkansas, and in Chico, California, on Malaria Investigations from 1919 to 1921; and again in Cincinnati at the old Stream Investigation Laboratory, Third and Kilgour, from 1921 until his retirement in 1941.

William Carey Purdy was born in Westover, Pennsylvania, on April 12, 1871. He was the youngest of five children in the family of William Byron Purdy, a Baptist minister, and Catherine Zimmerman Weight Purdy. His early education was in a small, one room county school and he spent many hours in the woods gaining a first hand acquaintance with nature. He attended Reidsburg Academy for two years and received a teachers certificate. After teaching in a country school two years, he entered Bucknell University in 1894. As his funds were scant he worked at odd jobs such as sign painting and shoe

repairing and he sold stereoscopes and views and gave chalk talks to organizations. After taking a year off to work he graduated with a B. S. degree in 1899. He married Alberta Simkins in December, 1900.

He taught briefly at Annapolis Preparatory School and Big Run High School in Pennsylvania, and from 1902 to 1907, he was science teacher at Slippery Rock State Teachers College. He received his M. S. degree from Bucknell in 1904, and from 1907 to 1912 was Professor of Biology in Geneva College at Beaver Falls.

In 1912 he entered the Massachusetts Institute of Technology where he was temporary instructor in Cryptogamic Botany and came under the influence of the outstanding sanitary biologist, Dr. William Thompson Sedgwick. Dr. Sedgwick took an interest in him and urged him to go into research work. Due to his urging and on his recommendation Mr. Purdy entered the Public Health Service to participate in the Potomac River Survey. While on this survey he noted the great purification capacity of the flats bordering the main river. His observations and his description of the activities of the biota in the utilization or purification of organic wastes have become classic.

In 1914, he was transferred to Cincinnati, to take part in the survey of the pollution and natural purification of the Ohio River. Natural purification was at this time a controversial subject. The biological studies which he carried out in cooperation with C. T. Butterfield served to demonstrate clearly and describe the role of the biota in the removal of organic wastes.

During and after World War I, he carried on studies directed toward control of malaria mosquitoes in Arkansas and California rice fields. In these studies he pointed out the importance of environmental control and the role of natural predators. Upon his return to Cincinnati, he participated in the study of the pollution and natural purification of the Illinois River. In cooperation with Messrs. Butterfield, Ruchhoft, and others, he carried out experimental studies of natural purification in polluted water and of

sewage purification. The results of each of these studies appeared in a series of papers, some thirty-seven in number, which appeared over a period of some eighteen years. During the latter years of his service, he participated in the comprehensive survey of stream pollution throughout the entire Ohio River Basin.

After retirement he carried on extensive investigations with Tubificid worms in which he had been interested for many years. He made extensive investigations of their life history and value in the purification of organic pollutants. He died at his home in Cincinnati on July 15, 1954.

His pattern of investigation and the principal features of his work in stream biology are regarded as landmarks of progress in sanitary science.

Publications of W. C. Purdy

1. Plankton studies of the Potomac River. Hygienic Lab. Bulletin No. 104, 1916.
2. Sanitary significance of bottom sediments. W. C. Purdy. Presented before Sanitary Engineering Section, Am. Pub. Health Assoc., Cincinnati, Ohio. Oct. 24, 1916.
3. Effect of plankton animals upon bacterial death rates. W. C. Purdy and C. T. Butterfield. Am. J. of Public Health, Vol. 8, No. 7, 499-505, 1918.
4. Malaria Endemicity of the rice districts of Louisiana and Arkansas, with some observations on types of mosquitoes breeding therein. J. C. Geiger, W. C. Purdy, and Lou Ina Bates. J. A. M. A., Vol. 71, 1283. Oct. 19, 1918.
5. Experimental mosquito control in rice fields. J. C. Geiger and W. C. Purdy. J. A. M. A., 72, 774. 1919.
6. Effective malaria control in a rice-field district with observations on experimental mosquito flights. J. C. Geiger, W. C. Purdy, and R. E. Tarbett. J. A. M. A., Vol. 72, 844-847. March 22, 1919.
7. Biological investigation of California rice fields relative to mosquito breeding. W. C. Purdy. Pub. Health Reports, Vol. 35, No. 44, 2556. Oct. 29, 1920.
8. Study of the pollution and natural purification of the Ohio River. I. The plankton and related organisms. W. C. Purdy. Pub. Health Bull. Vol. 131, 78 pp. 1923.
9. Algae. W. C. Purdy. 4th Annual Report Ohio Conf. on Water Purification. 1924. pp. 98-99.
10. The biology of stream purification. W. C. Purdy. Presented before 5th Annual Conf. of State Sanitary Engineers, Cincinnati, Ohio. May 28, 1924.
11. Biological investigation of California rice fields and attendant waters with reference to mosquito breeding. Pub. Health Bull. No. 145. 1924.
12. The biology of polluted water. W. C. Purdy. J. A. W. W. A., Vol. 16, No. 1, 45-54. 1926.
13. Relation of plankton to natural purification. A paper given in Cincinnati, Ohio, before the American Public Health Association. Oct. 1927.
14. Activities of plankton in the natural purification of polluted water. W. C. Purdy. Am. J. Public Health. Vol. 18, No. 4, 468-475, 1928.
15. A study of the pollution and natural purification of the Illinois River. II. The plankton and related organisms. W. C. Purdy. Pub. Health Bull. No. 198, 212 pp. 1930.
16. Some interrelationships of plankton and bacteria in natural purification of polluted water. C. T. Butterfield and W. C. Purdy. Ind. Eng. Chem., Vol. 23, No. 2, 213-218. 1931.
17. Methods for the biological examination of water. W. C. Purdy. Proc. 9th Annual Water Works School. Kansas Water Works Assoc., Univ. of Kansas, Lawrence, Kansas, Feb. 11-13, 1931. No. 3, 24-29.
18. Interpretation and use of biological data in the water works field. W. C. Purdy. Proc. 9th Annual Water Works School. Kansas Water Works Assoc., Univ. of Kansas, Lawrence, Kansas. Feb. 11-13, 1931. No. 3, 29-35.
19. Experimental studies of natural purification in polluted waters. IV. Influence of the plankton on the biochemical oxidation of organic matter. C. T. Butterfield, W. C. Purdy, and E. J. Theriault. Pub. Health Reports, Vol. 46, No. 8, 393-426. 1931.
20. The biological efficiency of a sewage polluted stream as observed in the Illinois River. W. C. Purdy. Presented before the Oklahoma Academy of Science. Stillwater, Oklahoma. Nov. 1931.

21. Some notes on the bulking of activated sludge as observed at the Tena-fly, N.J., sewage treatment plant, July-Aug. 1931. E.J. Theriault and W.C. Purdy. 1932. 35 pp.
22. Influence of the discharge of sewage on minute forms of stream life. W. C. Purdy. 6th Ohio Conf. on Sewage Treatment, Columbus, Ohio, Oct. 13-14, 1932. pp 21-29.
23. A biological study of the bulking of activated sludge at Tena-fly, N. J. W.C. Purdy. November 1932.
24. Disposal of sewage in the Potomac River. H. H. Crohurst and W. C. Purdy. Senate document No. 172, 72nd Congress, 2nd Session, 1933. 65 pp.
25. Results of algal activity, some familiar, others obscure. W. C. Purdy. J. A. W. W. A., Vol. 27, 1120-33. 1935.
26. A new plan for counting algae proposed at Ohio Conference. W. C. Purdy. Water Works Eng., Vol. 88, 1248-49. 1935.
27. Algae and their enumeration. W. C. Purdy. 15th Annual Report Ohio Conf. on Water Purification. pp 43-47. 1935.
28. Studies of sewage purification. IV. The use of chlorine for the correction of sludge bulking in the activated sludge process. R. S. Smith and W. C. Purdy. Pub. Health Reports, Vol. 51, No. 20, 617-623. 1936. Sew. Works J., Vol. 8, 223-230. 1936.
29. Experimental studies of natural purification in polluted waters. X. Reoxygenation of polluted waters by microscopic algae. W. C. Purdy. Pub. Health Reports, Vol. 52, No. 29, 945-978. July 16, 1937.
30. Limnological aspects of sewage disposal. W. C. Purdy. In Anniversary Book of the Federation of Sewage Works Associations; Modern Sewage Disposal. 1938. pp. 171-179.
31. Study of the pollution and natural purification of the Scioto River. R. W. Kehr, W. C. Purdy, J. B. Lackey, O. R. Plasak, and W. E. Burns. Pub. Health Bull. No. 276, 153 pp. 1941.
32. One - Parent progeny of Tubificid worms. W. C. Purdy. Science, Vol. 102, 182. Aug. 17, 1945.



Chester T. Butterfield began his career in the U.S. Public Health Service on August 23, 1915, when he reported for temporary duty at the old Kilgour Mansion located at Third and Kilgour Streets in Cincinnati. After the completion of a temporary assignment in a branch laboratory in Louisville, Kentucky, he returned to the Cincinnati Station where he remained until his retirement in 1951, with the exception of a brief tour of duty in the Army during World War I. During his 36 years of dedicated work in the Public Health Service he made many notable contributions to sanitary bacteriology. His pioneering work in water bacteriology provides the basis on which much of our present work now rests.

Chester T. Butterfield was born on a Missouri farm on July 30, 1890. His early life was a normal one for a farm boy at the turn of the century. He was fired with the desire for an education and was encouraged by his parents. He earned much of his own way through Cameron High School from which he graduated in 1909. While attending Missouri Wesleyan College he worked as a mechanic for an agency of the International Harvester Company during the summers and served as a laboratory assistant and instructor during the school years. He received

his B.S. degree in 1913 and his M.S. in 1914, with a major in Bacteriology and a minor in Chemistry. He attended summer school at the University of Missouri in 1914, and at the University of Chicago in 1915. During the 1914-15 school year he taught at the Wellsville Kansas High School. On July 16, 1916, he was married to Elsie M. Duncan.

At the Cincinnati Laboratory he took a very active part in the early investigations on stream pollution and natural purification, engaging in both the Ohio River surveys of 1914-1918 and 1939-1941. He also took a prominent place in the Illinois, Scioto, and Upper Mississippi River Surveys, and in the Lake Michigan studies. In cooperation with Purdy he demonstrated the role of protozoa in keeping bacterial populations active and efficient in the utilization of organic materials. He also investigated the die away of coliforms in polluted waters.

During World War I, he served in the Sanitary Corps and developed methods for the sterilization of surgical sutures. He also worked on the bacteriology of epidemic cerebrospinal meningitis and the classification of the meningococci.

In the 1920's and 30's he was engaged in two important series of studies; the experimental

evaluation of natural purification phenomena in streams and the fundamental aspects of sewage treatment methods and their laboratory control. He pioneered in isolating zooglycal bacteria from activated sludge and demonstrated that pure culture activated sludges consisting of zooglycal bacteria were capable of rapid and efficient removal of BOD from both synthetic and sterilized natural sewage. He was also actively engaged in the shellfish sanitation program and in a survey of the performance of representative water treatment plants located in 31 cities on the Ohio and other rivers of the midwest and eastern states. In 1920 he worked with Dr. W. B. Wherry on an etiological study of influenza. He also directed and participated in a study of the germicidal properties of quaternary ammonium compounds and their use and value for sanitizing milk and food utensils.

During the war years considerable time was devoted to the development of methods for water disinfection both at Army posts and in connection with field military operations. An intensive and comprehensive laboratory study was carried out on the bactericidal effects of free chlorine

and chloramines at different residual levels. The results of these studies were made immediately available to both the Army and Navy and guided them in obtaining the most effective and economical use of chlorine for water disinfection. They also established a scientific basis for municipal water chlorination practice. Definite relations were established between chlorine residual concentrations and the time of complete kill.

Following the passage of Public Law 845 in 1948, the Cincinnati Station was given divisional status under the title, "Environmental Health Center", and activities were reorganized under three main branches. Mr. Butterfield was placed in charge of the Research and Development Branch. His leadership and dedication to research were an inspiration to those in his organization. He shall be long remembered for his many outstanding accomplishments, his basic research, and his warm and human interest.

He is now residing at 1523 Northwest 11th Road, Gainesville, Florida.

Publications of Chester T. Butterfield

1. The Effect of Plankton Animals Upon Bacterial Death Rates. W. C. Purdy and C. T. Butterfield. *Amer. Jour. of Public Health*, Vol. 8, No. 7, 499-505. July, 1918.
2. Sterility of Catgut. C. T. Butterfield and L. F. Ey. *Jour. Amer. Medical Assn.*, Vol. 72, 1736-37. June 14, 1919.
3. Differentiation Between Various Strains of Meningococci by Means of the Agglutination and the Absorption of Agglutinins Tests. C. T. Butterfield and M. H. Neill. *Hygienic Laboratory Bulletin* No. 124, November, 1920.
4. Effect of Freezing and Thawing Upon the Antibody Content of Anti-meningococcus Serum. C. T. Butterfield. *Hygienic Laboratory Bulletin* No. 124, November, 1920.
5. Inhalation experiments on Influenza and Pneumonia, and on the Importance of Spray-borne Bacteria in Respiratory Infections. William B. Wherry and C. T. Butterfield. *Jour. of Infectious Diseases*, Vol. 27, No. 4, 315-326. October, 1920.
6. Inhalation Experiments on Influenza and Pneumonia, and on the Importance of Spray-borne Bacteria in Respiratory Infections*. William B. Wherry and C. T. Butterfield. *Public Health Reports*, Vol. 36, No. 25, 1443-1459. June 24, 1931.
7. The Bacteriological Examination of Water. C. T. Butterfield. *Trans. of the Third Ohio Conference on Water Purification* (1923). Reprinted in the *Canadian Engineer*, Vol. 49:500, October 27, 1925, under the title of "Water Laboratory Methods".
8. Experimental Studies of Bacterial Death Rates in Polluted Waters. C. T. Butterfield. *Jour. of Bacteriology*, Vol. 16, 257-267. Oct. 1928.
9. Experimental Studies of Natural Purification in Polluted Waters. I. Apparatus and Technique for the Study of Biochemical and Other Oxidations in Liquids. E. J. Theriault and C. T. Butterfield. *Public Health Reports*, Vol. 44, 2253-2267, Sept. 20, 1929.
10. Experimental Studies of Natural Purification in Polluted Waters. II. Development of a Suitable Dilute Medium. C. T. Butterfield. *Public Health Reports*, Vol. 44, 2647-2658, November 1, 1929.
11. Experimental Studies of Natural Purification in Polluted Waters. III. A Note on the Relation Between Food Concentration in Liquid Media and Bacterial Growth. C. T. Butterfield. *Public Health Reports*, Vol. 44, 2865-2872. November 22, 1929.
12. Some Interrelationships of Plankton and Bacteria in Natural Purification of Polluted Water. C. T. Butterfield and W. C. Purdy. *Industrial and Engineering Chemistry*, Vol. 23, 213. February 1931.

*A revision of paper 5 prepared by junior author for Public Health Reports.

13. Experimental Studies of Natural Purification in Polluted Waters. IV. The Influence of the Plankton on the Biochemical Oxidation of Organic Matter. C. T. Butterfield, W. C. Purdy, and E. J. Theriault. Public Health Reports, Vol. 46, 393-426. February 20, 1931.
14. Experimental Studies of Natural Purification in Polluted Waters. V. The Selection of Dilution Waters for Use in Oxygen Demand Tests. E. J. Theriault and P. D. McNamee and C. T. Butterfield. Public Health Reports, Vol. 46, 1084-1116, May 8, 1931.
15. The Selection of a Dilution Water for Bacteriological Examinations. C. T. Butterfield. Jour. of Bacteriology, Vol. 23, 355-368. May 1932. Reprinted as paper VII - Experimental Studies of Natural Purification in Polluted Waters - in Public Health Reports, Vol. 48, 681-691. June 16, 1933.
16. Suggested Procedures for the Presumptive Test in the Determination of the Coli-aerogenes Group. C. T. Butterfield. Jour. of the Amer. Public Health Association, Vol. 23, 343-349, April 1933.
17. The Catalysis of Air Oxidation by Iron Salts, Phosphates, and Pyrophosphates. E. J. Theriault, C. T. Butterfield and P. D. McNamee. Jour. of the American Chemical Society, Vol. 55, 2012-2024. May 1933.
18. A Note on the Food Habits of Colpidium. C. T. Butterfield. Public Health Reports, Vol. 48, 814-18. July 14, 1933.
19. Observations on Changes in Numbers of Bacteria in Polluted Water. C. T. Butterfield. Sewage Works Jour., Vol. 5, 600-622. July 1933.
20. Some Observed Effects of Dilution on the Bacterial Changes in Polluted Waters. J. K. Hoskins and C. T. Butterfield. Sewage Works Journal, Vol. 5, 763-773. September 1933.
21. Comparison of the Enumeration of Bacteria by Means of Solid and Liquid Media. C. T. Butterfield. Public Health Reports, Vol. 48, 1292-1297. October 20, 1933.
22. Studies of Sewage Purification. II. A Zoogloea-forming Bacterium Isolated from Activated Sludge. C. T. Butterfield. Public Works, Vol. 65, 15. May and June 1935. Reprinted in Public Health Reports, Vol. 50, 671-684. May 17, 1935.
23. Determining the Bacteriological Quality of Drinking Water. J. K. Hoskins and C. T. Butterfield. Jour. of the Amer. Water Works Assns., Vol. 27, 1101-1109. Sept. 1935.
24. Biological and Bacteriological Relationships in Water Purification and Sewage Treatment. C. T. Butterfield Biennial Report, Kansas Water and Sewage Works 1934-1935, 106-109.
25. Studies of Sewage Purification. VI. Biochemical Oxidation by Sludges Developed by Pure Cultures of Bacteria Isolated from Activated Sludge. C. T. Butterfield, C. C. Ruchhoft, and P. D. McNamee. Sewage Works Jour., Vol. 9, 173-196. March 1937.
26. The Oxidation of Sewage by Bacteria in Pure Culture. C. T. Butterfield. Jour. of Bacteriology, Vol. 34, 207-219. August 1937.
27. Studies of Sewage Purification. VII. Biochemical Oxidation by Activated Sludge. C. C. Ruchhoft, P. D. McNamee, and C. T. Butterfield. Public Health Reports, Vol. 53, 1690-1718. Sept. 23, 1938. Also in Sewage Works Jour., Vol. 10, 661. July 1938.
28. Studies of Sewage Purification. VIII. Observations on the Effect of Variations in the Initial numbers of Bacteria and of the Dispersion of Sludge Flocs on the Course of Oxidation of Organic Material by Bacteria in Pure Culture. C. T. Butterfield and Elsie Wattie. Public Health Reports, Vol. 53, 1912-1934. October 28, 1938. Sewage Works Journal, Vol. 10, 815. September 1938.
29. Studies of Sewage Purification. IX. Total Purification, Oxidation, Adsorption, and Synthesis of Nutrient Substrates by Activated Sludge. C. C. Ruchhoft, C. T. Butterfield, P. D. McNamee, and Elsie Wattie. Public Health Reports, Vol. 54, 468. March 24, 1939.
30. Some Functions of Bacteria in the Purification of Polluted Water. C. T. Butterfield. Jour. of Bacteriology, Vol. 39, 527. May 1940.
31. Studies of Sewage Purification. XV. Effective Bacteria in Purification by Trickling Filters. C. T. Butterfield and E. Wattie. Public Health Reports, Vol. 56:2445-64. Dec. 26, 1941. Sewage Works Journal, Vol. 13:639-58. 1941.
32. Notes on the Relation Between Coliforms and Enteric Pathogens. R. W. Kehr and C. T. Butterfield. Public Health Reports, Vol. 58:589-607. April 9, 1943.
33. Influence of pH and Temperature on the Survival of Coliforms and Enteric Pathogens When Exposed to Free Chlorine. C. T. Butterfield, E. Wattie, S. Megregian, and C. W. Chambers. Public Health Reports, Vol. 58:1837-66. Dec. 17, 1943.
34. Relative Resistance of Esch. coli and Eber. typhosa to Chlorine and Chloramine. C. T. Butterfield and E. Wattie. Public Health Reports, Vol. 59:1661-71. Dec. 29, 1944.
35. Influence of pH and Temperature on the Survival of Coliforms and Enteric Pathogens When Exposed to Chloramine. C. T. Butterfield and E. Wattie. Public Health Reports, Vol. 61:157-92. Feb. 8, 1946.
36. Determining the Bacterial Quality of Water. C. T. Butterfield. Organo Oficial de la Asociacion Interamericana de Ingenieria Sanitaria, Vol. 2:89-93. 1948.
37. Bactericidal Properties of Free and Combined Available Chlorine. C. T. Butterfield. Jour. Amer. Water Works Assn. Vol. 40:1305-12. 1948.
38. Bactericidal Properties of Chloramines and Free Chlorine in Water. C. T. Butterfield. Public Health Reports, Vol. 63:934-40. July 16, 1948. J. A. W. W. A., Vol. 40:1305-12. 1948.
39. Bactericidal Efficiency of Quaternary Ammonium Compounds. C. T. Butterfield, E. Wattie, and C. W. Chambers. Public Health Reports, Vol. 65:1039-56. August, 18, 1950.

BLANK PAGE

CONTENTS

Page

EFFECTS OF THE DISCHARGE OF RADIOACTIVE MATERIALS ON AQUATIC LIFE

Radiobiological studies at the Eniwetok test site and adjacent areas of the Western Pacific - Lauren R. Donaldson	1
Accumulation of radioactive pollutants by marine organisms and its relation to fisheries - Walter A. Chipman	8
The significance of the uptake of radioisotopes by fresh-water fishes - Richard F. Foster.	15
Investigation of the effects of radioactive material on aquatic life in Canada - Ivan L. Ophel	21
Problems related to disposal of radioactive wastes in estuarine and coastal waters - D. W. Pritchard	22
Pollution problems created by power reactors and other uses of atomic energy - Conrad P. Straub	33
Panel Summary - Lauren R. Donaldson	40

EFFECTS OF PESTICIDES ON AQUATIC LIFE

A conservationist's views on the new insecticides - Clarence C. Cottam	42
What are the side effects of the imported fire ant control program? - I. B. Byrd	46
Are the insecticides required for insect control hazardous to aquatic life? - Clarence H. Hoffman	51
Effects of forest insect spraying on trout and aquatic insects in some Montana streams - Richard J. Graham	62
Aerial forest spraying in Canada in relation to effects on aquatic life - F. E. Webb	66
Effects on young salmon of forest spraying with DDT - C. J. Kerswill, P. F. Elson, M. H. A. Keenleyside, and J. B. Sprague	71
The retention of DDT by trout and whitefish - Oliver B. Cope	72
The toxicity of organic phosphorus and chlorinated hydrocarbon insecticides to fish - Croswell Henderson, Q. H. Pickering, and C. M. Tarzwell	76
Some effects of pesticides on marine arthropods and mollusks - Victor L. Loosanoff	89
The toxicity of organic insecticides to Daphnia - Bertil G. Anderson	94

	Page
Toxicity of various herbicidal materials to fishes - Carl E. Bond, Robert H. Lewis, and John L. Fryer	96
Panel Summary - Clarence C. Cottam	102
 <u>ENVIRONMENTAL REQUIREMENTS FOR AQUATIC LIFE</u>	
The oxygen requirements of fish - F. E. J. Fry	106
Thermal requirements of fish = three decades of study, 1940-1970 - J. R. Brett	110
Settleable solids, turbidity, and light penetration as factors affecting water quality - Alfred F. Bartsch	118
Environmental requirements of oysters in relation to pollution - Paul S. Galtsoff	128
 <u>PRACTICAL APPLICATION OF BIOLOGICAL FINDINGS IN POLLUTION ABATEMENT</u>	
A conservationist's views on the practical application of biological findings - Ernest Swift.	135
What does the sanitary engineer expect of the biologist in the solution of water pollution problems? - Erman A. Pearson	139
The use of bioassays by the water pollution control agency - G. E. Burdick	145
What does industry expect of the biologist and how can his findings be applied to industrial waste problems? - Harry W. Gehm	149
Application of biological findings to water pollution problems in Louisiana - K. E. Biglane	152
Biological aspects of industrial waste problems - Charles E. Renn	156
 <u>MARINE AND ESTUARINE POLLUTION PROBLEMS</u>	
Effects of pulp and paper mill wastes on the marine environment - Michael Waldichuk	160
Marine pollution problems in the Southern California area - Claude E. ZoBell	177
Pollution problems along the Gulf Coast - Gordon Gunter	184
Ecological effects of sewage pollution in Biscayne Bay, Florida: Distribution of coliform bacteria, chemical nutrients, and volumes of zooplankton - J. Kneeland McNulty, Ernest S. Reynolds, and Sigmund M. Miller	189
Some aspects of pollution, parasitism, and inlet restriction in three New Jersey estuaries - Thurlow C. Nelson	203
Marine pollution problems in the North Atlanta area - Bostwick H. Ketchum	212
Panel Summary - Thurlow C. Nelson	218
An administrator looks at the pollution problem - Seth Gordon	222

	Page
Research for the establishment of water quality criteria for aquatic life - Clarence Cottam and Clarence M. Tarzwell	226
Summary of Second Seminar on Biological Problems in Water Pollution - Ernest Swift . .	233
 <u>INFORMAL GROUP DISCUSSIONS</u>	
Biological indicators of organic enrichment in fresh water - A. R. Gaufin	237
Biological indicators of organic enrichment in marine habitats - J. L. Mohr	237
Advanced specialized technical training in pollution biology - H. W. Jackson	239
Identification of toxicants by physiological responses of fishes - Charles M. Weiss	240
Pollution control by chemicals and some resulting problems - Frank F. Hooper	241
Bioassay procedures, aims, and equipment - Crosswell Henderson	246
How should we determine dissolved oxygen criteria for fresh water fishes? - Peter Doudoroff	248
The problem of nuisance growths due to organic enrichment - H. Heukelekian	250
The significance of periphyton on natural and artificial substrates - George H. Lauff . . .	251
The pulp and paper mill waste problem - Hayse H. Black	253
Composition of sulfite waste liquor - E. F. Eldridge	255
The conversion of spent sulfite liquor into useful products - Bernard F. Lueck	257
Effective methods for collecting and recording data from water pollution surveys - William Marcus Ingram	260
Graphic presentation of biological data for water pollution survey reports - William Marcus Ingram and Alfred F. Bartsch	260
Effective methods for collecting and recording data from water pollution surveys - Eugene W. Sarber	263
Biological stream survey data - Charles B. Wurtz	266
How can the biologist best function in water pollution surveys? - Carlos M. Fetterolf . . .	267
The effects of erosion silt and other inert materials on aquatic life - John Wilson	269
Herbicides - Charles R. Walker	272
<u>OIL REFINERY WASTE PROBLEMS</u> - Robert A. Lafleur	273
Refinery waste problems - Robert A. Lafleur	273
Toxicity bioassay of oil refinery effluents in Oklahoma - Troy C. Dorris, William Gould, and Charles R. Jenkins	276

RADIOBIOLOGICAL STUDIES AT THE ENIWETOK TEST SITE AND ADJACENT AREAS OF THE WESTERN PACIFIC

Lauren R. Donaldson - Laboratory of Radiation Biology,
University of Washington, Seattle, Washington

ABSTRACT

The nuclear experiments conducted at Bikini and Eniwetok Atolls have produced radioactive products that are deposited upon the islands of the atolls and into the water of the lagoons or open sea. Since July 1946, studies carried on in the atolls have followed the biological fate of "tagged" materials. It has been possible not only to measure the amount of such radioactive material, but to follow the movement and biological cycling in the extremely complex terrestrial and aquatic environments of the tropical atolls.

The results of successive studies over a period of twelve years have shown that biological activity is often of greater importance than physical factors in the distribution and localization of radioactive products in a marine environment. Certain organisms, notably algal and planktonic forms, remove minerals from the water within hours. Much of the uptake is by absorption.

The amount of uptake by invertebrates and fish is primarily dependent on feeding habit, indicating the importance of food chains in the distribution of radioactive materials.

Varying degrees of selective uptake and concentration of isotopes are found. Marine plankton, tiny plants and animals living in the sea, blot up the radioactive materials almost immediately upon their production. Radioactivity of the plankton is several thousand times that of the water. A marine reef alga, *Asparagopsis*, concentrates ^{131}I from the sea water by a factor of hundreds of thousands within a few days after the iodine is available. Some forms, although concentrating the radioactive materials, are less selective.

Levels of radioactivity in fish tissues are generally in the following descending order: (1) digestive tract with content, (2) liver, (3) skin, (4) bone, (5) muscle. The radioactivity in muscle and bone is often at or near back-

ground levels when there are significant levels in the digestive tract, skin or liver. Isotopes found in fish include Zn^{65} , Fe^{55} , $\text{Co}^{57-58-60}$ and Mn^{54} .

Comparable tissues in the invertebrates fall in the same general pattern. Most of the radioactivity found in mollusk shells and corals is associated with surface contamination of algal films.

Terrestrial island communities are studied in association with the marine environment. Translocation of radioactive products from sea to land and vice versa have been observed. There has been leaching from the land following rains, and increases in radioactivity have been found associated with organic materials on beaches months after initial contamination.

Biological effects directly attributable to the injurious effects of radioactive contamination have not been evident. Competition is so severe that any injured individuals are likely to be eliminated and replaced before they are observed.

It is clear from the rapidity of uptake of radioisotopes that there is a great thirst for minerals by organisms in the marine environment. The practical implication, therefore, is that fertilization of specific areas with mineral products could overcome one of the limiting factors to biological productivity. Under some conditions suitable isotopes could be used as an index of the efficiency of such fertilization.

Understanding the role of nutritive materials, especially trace elements, in a marine environment surely points to the possibility for applying the methods of study and the techniques to fresh-water areas. Such a program will lead to increasing the food production of streams, lakes and ponds in as spectacular a fashion as similar studies have with farm crops.

The nuclear experiments conducted at Bikini and Eniwetok Atolls in the Marshall Islands are more than experiments to measure physical forces; they are unparalleled scientific experiments involving a great number of scientific disciplines. Among the disciplines represented,

biology is taking a leading role.

Biologists have been a part of this scientific team activity since the inception of the atomic tests at Bikini in 1946. Studies with the radioactive materials resulting from the weapons

tests and deposited in the sea and on the islands have made it possible to follow the biological cycling of these materials even where they have become diluted to infinitesimal quantities, by standards of ordinary chemical analysis. Hines (1951) has described the general problem of evaluation of this research.

Much attention has been given to the more immediate effects of the weapons tested upon the fauna and flora of the atolls but such studies, important as they are, have not occupied the total planning, thinking and execution of the program of biological studies. Extensive investigations using the facilities, personnel, and equipment available at the test organizations and test sites have answered many questions relating to the economy of the sea, have opened up new knowledge of the life zones of coral atolls, and have reshaped in important ways some of the basic concepts of biological science. By using the radioactive or "tagged" minerals available and the methods of microchemist and physicist, biology has advanced to a more exact science.

Since the pre-test preparations for Operation Crossroads in 1946, representatives of marine biology, oceanography, and geology have made intensive studies at some of the atolls in the northern Marshall Islands, with the result that few oceanic areas have been studied as intensively by such a variety of specialists as have Bikini and Eniwetok Atolls.

Notable contributions have been made to the knowledge of the geology of atolls by Tracey et al. (1948) and Ladd (1952). Von Arx (1954) has reported on the water circulation in Bikini lagoon, and the action of ocean waves on Bikini reefs has been described by Munk and Sargent (1954). Robinson (1954) made studies of the sea temperature in the Marshall Islands. Barnes et al. (1948) reported on the ocean circulation in the Marshall Islands area, and Mao and Yoshida (1954) described the physical oceanography of the same region. Schultz et al. (1953) have described the fishes of the Marshall and Mariana Islands. The plants of Bikini, etc. were studied and reported on by Taylor (1950), Fosberg (1953), St. John (1949), and Biddulph (1952). Dawson (1957) has reported on the algae of Eniwetok Atoll.

Studies on the distribution of radioactive minerals produced by the atomic tests conducted in the Marshalls have been published by the Laboratory of Radiation Biology,* University of Washington.

An atoll may be described as a roughly oval, coralline reef rising 15,000 feet above the ocean floor. Within the surrounding reef there is enclosed a shallow lagoon generally with a maximum depth of about 180 feet. The lagoon is open to the ocean by one or more passes cutting through the reef, most of which is awash except at low tides. Emergent land consists of low sandy islands with an elevation seven to ten feet above sea level; elevations as high as twenty feet are rare. The islands occupy only a small fraction of the total area of an atoll. Bikini lagoon covers 229 square miles (Handbook on the Trust Territory of the Pacific Islands) and has a dry land area of two and a third square miles divided among some thirty-six islands and islets; Eniwetok lagoon covers 388 square miles, has a dry land area of two and one-fourth square miles, and forty islands.

These atolls lie in a zone of the northeast trade winds. Because of the constancy of direction of the winds, there are distinct differences in reef form between the windward and leeward sides of the atoll. The windward side is generally considered the region of most rapid growth and is characterized by a narrow, slightly elevated ridge near the reef edge, the Lithothamnion ridge, which is lacking on the leeward side. The latter drops off vertically to depths of 100 to 200 feet on the seaward side, while the seaward slope of the windward reef falls away at an angle of about forty-five degrees.

On the reef and in the lagoon there is an abundance of colorful plant and animal life in which the keen competition between different species for space and food is very evident. On every hand there is evidence of rapid growth and simultaneous destruction. Masses of reef-building coral are competing with each other and with the coralline marine algae for space. one often overgrowing the other. Schools of green parrotfish gnaw wide scratches on the coral. Fleshy patches of algae are pressed tightly against the surface of the coral to hold against the surges of the water pushed across the reef by the crashing breakers. Sea urchins

*Formerly the Applied Fisheries Laboratory

and clams grind niches into the hard coral, some of them constantly feeding on the cover of bacterial and algal film which is as constantly being replaced. The clams, the corals, some small fish and other forms are ceaselessly removing from suspension in the water the small, often microscopic, plants, animals, and bits of debris which make up the plankton. In regions of quieter water, where sand has been deposited, sea cucumbers and spider snails, among the larger forms, turn the sand again and again in their gleaning for food.

Large schools of goatfish, mullet, surgeonfish, and other plant and plankton feeders are a common sight. Preying on unwary or disabled members of these schools are the carnivorous fish -- the groupers, tuna, jacks and sharks. Ultimately the waste products and carcasses of these and other carnivores are returned to the lagoon and reef to complete the cycle.

Little or no time is lost between steps in the biological cycling of materials for there is not only an abundance of organisms but also a wide variety of species -- some 700 among the fishes alone (Schultz et al. (1953)) -- so that whatever is not utilized by one is quickly taken by another. There is here a perfect economy of use of substances essential to life.

Available substances are rapidly taken up by the biota, never remaining long in the water to be diluted and washed away. This is dramatically demonstrated following an atomic test in which radioactive materials are deposited in the water. Within hours, the great bulk of these materials is to be found in the living organisms. Plankton and some of the algae, which are the key organisms in the food chain, may concentrate within themselves more than a thousand times the amount of radioactive substances found in the sea water. The herbivorous fish and invertebrates have lower concentrations of radionuclides at any given time than do the plants on which they feed, and progressing along the food chain to the carnivores the concentrations become lower and lower. Within each organism there is a differential concentration from tissue to tissue, the digestive organs having a higher concentration than the other tissues, where a more selective deposition as to specific isotopes has taken place.

More specifically, plankton, the oceanic plants and animals that drift about passively

with little or no resistance to water movements, may influence greatly the distribution of radioactive materials in the sea. These forms include many groups of organisms from the simple one-celled plants to the larval forms of vertebrates.

Plankton acquire radioisotopes by absorption, adsorption, or both. Plankton, especially phytoplankton, present a greater absorptive surface to the environment than any other group of marine organisms. Thus, the major initial concentration of radioactive isotopes probably occurs in the phytoplankton -- the same organisms which comprise the foundation of the food chain in the sea. The isotopes especially concentrated by these forms are, for the most part, representatives of those elements which tend to form strong complexes with organic material. They include most of the anionic radioisotopes, with the exception of iodine, and the cationic radioisotopes produced by neutron induction including radioactive zinc, cobalt, iron and manganese. All of the cationic radioisotopes concentrated in the plankton are biologically important elements comprising the essential parts of enzyme systems and, in one case at least, an essential vitamin.

The levels of radioisotopes present in the plankton vary with time after release of the radioactive materials, mainly because of the variation in availability due to physical decay of the individual radioisotopes (UWFL-53). In general, however, plankton contain the three radioactive isotopes of cobalt, Co^{57} , Co^{58} and Co^{60} , at a level of 11 to 50 percent of the total radioactivity. Zn^{65} is present at a level of 12 to 47 percent; Fe^{55-59} at a level of 1 to 40 percent; Mn^{54} in trace amounts, and the fission products Zr^{95} - Nb^{95} at levels of 3 to 44 percent; Ru^{106} - Rh^{106} from 0 to 7 percent; Ce^{144} - Pr^{144} , 0 to 13 percent; and Cs^{137} in trace amounts, if present at all (UWFL-54). Sr^{90} - Y^{90} has not been found in plankton.

Once the radioactive materials have been absorbed or adsorbed by the plankton, their distribution is likely to be greater both vertically and horizontally than if distribution were solely dependent upon the surface currents. One reason for a greater distribution would be that absorption by plankton makes the radionuclides available to larger organisms which can move beyond the current's boundaries. Similarly these materials also become available to the local

resident populations and, as they are recycled through the food chain, the effect is a delay in their distribution away from the original area of contamination. Another factor influencing the distribution of radioactive materials by plankton is their diurnal vertical migration. If this migration were great enough to take the plankton below the current stream, it would extend the vertical distribution and also slow down the horizontal distribution, because the plankton would be moving horizontally more slowly than the water.

Plankton may carry radioactive materials from the deeper waters of the lagoons to the surface or even up onto the reefs and eventually to the islands by vertical migration. At Bikini it has been observed, for example, that these materials were picked up by the plankton in the deeper waters of the lagoon during the daytime. The concentrated radionuclides in the plankton were then transported to the surface by the diurnal vertical migration of these minute forms. At the surface, their presence at night caused the surface radiation content to increase measurably over the daylight readings. The fouling organisms on the bottoms of the ships and the plankton feeders on the reef became increasingly radioactive at night as the transport of the radioactive products continued.

It can be said then that plankton may cause the distribution of radionuclides in the sea to be different from that which would be expected from the distribution by currents alone in the following respects: (1) a delay in the movement from the area of original contamination, (2) a slower down-current movement, (3) a limited dispersion up-current or beyond the currents' boundaries, (4) a greater vertical distribution, and (5) an over-all greater dispersion of relatively lower concentrations.

Aquatic plants or algae may be free-floating (as are the phytoplankton), attached to the reefs, or growing in the shallow water. Just as do land plants, the algae contribute to the food supply of animal populations. Minerals as well as organic materials, concentrated and incorporated into the algae, are passed on in the food chain to the animals that feed upon them. Thus the radioactive materials pass through the algae to the animals in the normal course of food gathering.

The affinity of algae for some of the radioisotopes is well known. For example, Aspara-

gopsis, a marine alga found on the reefs at Bikini and Eniwetok, has a great affinity for iodine (UWFL-44). In the presence of I^{131} Asparagopsis becomes radioactive. This alga is a succulent morsel sought by fishes; thus the I^{131} passes to the fish and along the food chain.

The land plants of the tropical islands of the Pacific atolls become contaminated with radioactive materials in two ways: (1) by fallout of material from the air or from the rain water with direct absorption through the leaves, and (2) by absorption from the soil.

The soils of the atolls are generally deficient in potassium. This deficiency speeds the uptake of Cs^{137} by the plants. Although Ce^{144} is present in the soils it is so firmly bound there that little is available to the plants.

The radioisotopes remain concentrated in the top two inches or less of soil. The rooting habits of the plants, therefore, are associated with uptake of the radioisotopes. The plants with feeder roots close to the surface thus take up more of the radionuclides than do those with deeper root systems.

While all of the tissues of the plants may contain radioisotopes, the major concentrations are to be found in the leaves, bark, seeds, corms or nuts. Since these are the most used portions of the plant for animal foods, the plants pass the radioactive materials on to the animals where they are incorporated into the animal tissue, only to be released in the normal biological cycle and passed back to the land for re-absorption.

The invertebrates, or animals without backbones, make up the great bulk of the animal life of an atoll. The role of these animals in the cycling of radioactive materials in an atoll is as varied as the invertebrate forms. Sea cucumbers have been compared with earth worms in their ceaseless turning of the gravel and sand as they obtain their nutriment from bacteria and algae. Corals and clams remove microorganisms and particulate matter from the water and also are host to the unicellular algae, Zooxanthellae, which are found in their tissues. The Zooxanthellae may be thought of as a vast reservoir of trapped plankton. Their relationship to their host is not completely understood but it is probable that they play an important part in the removal of phosphate wastes. Corals and clams

are eroded by algae and sponges, which bore holes in the skeleton or shell, thus contributing to a return of carbonates to the water. Crabs, sipunculid worms and others also attack the skeleton of the corals. Some of the land crabs contribute to the deposition of radioisotopes from the sea onto the islands by dragging fish and algae ashore when feeding. In short, within the invertebrates and their symbionts alone complete biological cycles occur from land to sea and back again, from inorganic substances to organic and back again.

The fishes of the waters in and about the Marshall Islands have received a major share of the attention in the study of the biological cycling of radioactive materials (AECD-3446, UWFL-46, UWFL-47, UWFL-49, UWFL-51, UWFL-55). Despite detailed study, the great variety of fishes with a correspondingly great variation in feeding habit make this a very difficult area in which to summarize results.

In general, the fishes may be divided by feeding habit into three groups: the herbivores, omnivores and carnivores. Since the herbivores feed directly on the algae, the radioisotopes concentrated from the water by the algae are passed on directly to the fish, and from the fish to the animal eating the fish. The herbivores, represented by such fishes as the surgeonfish and parrotfish, have the greatest amount of radioactivity of the three major groups.

Omnivorous fish such as the damselfish have less contamination than have the herbivorous fish, for they feed on more complex organisms.

The herbivorous and omnivorous fish tend to concentrate the same isotopes found in the plankton except for the radioisotopes which are taken up only in trace amounts by these animals. Zn^{65} usually accounts for 50 percent or more of the total radioactivity in the organs of these fish and Fe^{55-59} comprises a major part of the remaining activity. The radioactive isotopes of cobalt account for 7 to 20 percent of the radioactivity and Mn^{54} 2 to 6 percent.

The minimum concentrations of radioactive material are found in the carnivores, for these fishes, like the reef-dwelling groupers, or the roaming carnivores, like the tuna and barracuda, obtain their "tag" of radioactive material only after it has been passed through a number of living forms which select, retain, or reject

various radioisotopes. With the passage of time longer-term studies indicate that several years after a single contamination of an area the carnivorous fish contain the greatest amount of radioactivity.

The carnivorous fish such as tuna and bonito, caught in the open ocean, contain Zn^{65} at the highest levels of any of the three groups of fish. In these animals Zn^{65} accounts for 75 to 92 percent of the total radioactivity; Fe^{55-59} , 6 to 25 percent; the cobalt radioisotopes, 1 to 3 percent; and Mn^{54} , less than 1 percent.

In all species of fish, the greatest amount of radioactivity is found in the alimentary tract, with liver, skin, bone and muscle having lesser amounts in descending order. Skin and bone are quite similar in the amounts present, and usually the radioactivity averages about twice that found in the muscle. The liver may have two to nine times as much radioactivity as the bone or skin, and the alimentary tract contains two to four times as much as the liver.

Unlike the fishes--the aquatic vertebrates--the land vertebrates are limited in both kinds and numbers on the islands of the atolls used for the experiments. Two kinds of birds, the fairy or white tern and the common noddy tern and the insular field rat are sufficiently abundant and have adequate distribution to be useful as study material.

The terns gather their food from the sea, where they feed mostly upon small pelagic fish, which in turn feed upon plankton. Radioisotopes not absorbed and retained by the birds may be dropped upon the islands in the resting and nesting areas. This transfer of radioactive materials from the sea to the land by the fish-eating birds is a useful way to measure the reverse flow or "uphill" transfer of minerals from sea to land. An indirect effect is the change of availability of radioactive materials following fertilization of the soil by the birds.

Studies of the rats on the islands near the detonation sites have proven to be extremely useful in evaluating the over-all effects of atomic weapons. Since they are confined to the small islands and must both live and eat on the contaminated areas, they may receive both external as well as internal exposure to radiation.

The highest concentration of radioactive materials in the rats is in the bone, with liver

and kidney somewhat lower. The skin, muscle, lung and intestinal tract are, in general, lowest in radioactive content. The relative levels in the various tissues vary with time, although the general pattern is that noted above.

This species of rats is essentially herbivorous; they obtain their food from the land plants, seeking out and eating the seeds of grasses, sedges, sand burrs, and leaves of some of the succulent plants.

The plants upon which the rats feed concentrate Sr^{90} and Cs^{137} . These radioisotopes account for approximately 100 percent of the radioactivity within the organs of these animals except immediately after shot when additional short lived radioisotopes are also present. During this time, I^{133} , I^{131} may be present in very high levels in the thyroids.

By following the pattern of gross radioactivity it has been possible to delineate the broad trends in the distribution of radioactive materials in an atoll and its surrounding area. There remains much that can profitably be done to amplify this area, but enough is now known to point the need for increased attention to the task of following the distribution of specific isotopes. Thus, more can be learned about selective absorption of elements by different organisms, and an unparalleled opportunity is presented to study the role of trace elements in the marine environment.

In the remote atolls of the Marshall Islands important contributions to biology have been made; the need now is to apply the knowledge, techniques and skills to increase the produc-

tive capacity of our fresh-water areas. There is every evidence that the rewards in increased food production from aquatic resources will rival or exceed the spectacular results that have been obtained from applying these new concepts to agriculture.

In short, the Pacific testing areas comprise a laboratory in which the biologists have worked with the secondary but long-range problems incident to the peaceful employment of atomic energy. Conditions there are exceedingly fine for the study of the disposition and distribution in nature of the radioactive by-products of such employment.

Biologists have been participants in this scientific team activity since the inception of the atomic tests at Bikini in 1946. This participation has been of almost revolutionary importance to the biologists, for it has given them unprecedented opportunity to observe the biological cycling of radioactive materials deposited on sea and land in the detonation of atomic weapons. But twelve years of field and laboratory work also have demonstrated that the problems of the biologists are those that have fundamental significance in the larger matter of proper planning for the future use of atomic energy. Experience in the Pacific has permitted the biologists to develop new techniques of investigation and has suggested other areas in which the techniques may be tested and applied. The program in the Pacific, permitting the biologists to use the facilities of the test organizations at the test sites, has answered many questions relating to the economy of the sea, has opened up new knowledge of the life zones of coral atolls, and has reshaped in important ways the basic concepts of biological science.

REFERENCES

- Applied Fisheries Laboratory. 1950. Radiobiological survey of Bikini, Eniwetok, and Likiep atolls -- July-August, 1949. Off. Tech. Services, U. S. Dept. Comm. AEC Report AECD-3446.
- Barnes, C.A. et al. 1948. Ocean circulation in the Marshall Islands area. *Am. Geophys. Union Trans.* 29: 871-76.
- Biddulph, O. and R. Cory. 1952. The relationship between Ca^{45} , total calcium and fission product radioactivity in plants of *Portulaca oleracea* growing in the vicinity of the atom bomb test sites on Eniwetok atoll. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-31.
- Bonham, K. 1958. Radioactivity of invertebrates and other organisms at Eniwetok atoll during 1954-55. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-53.
- Dawson, E. 1957. An annotated list of marine algae from Eniwetok atoll, Marshall Islands. *Pacific Science*.
- Donaldson, L. R. et al. 1956. Survey of radioactivity in the sea near Bikini and Eniwetok atolls -- June 11-21, 1956. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-46.
- Fosberg, F. R. 1953. Vegetation of central pacific atolls. *Atoll Research Bull.* 23: 1-26.
- Handbook on the trust territory of the Pacific Islands. 1949. Navy Department, Office of the Chief of Naval Operations.
- Held, E. E. 1957. Land crabs and radioactive fallout at Eniwetok atoll. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-50.

Hines, N. O. 1951. Bikini report. The Scientific Monthly, v. 72, No. 2: 102-13.

Ichikawa, T. and Y. Hiyama. 1954. Adsorption of radioactivity on mucus of fish. Report III-5 on the effects of radioactivity to the Special Committee of the Science Council of Japan. Tokyo.

Ladd, H. S. 1952. Foundation of Eniwetok atoll. Bull. Geol. Surv. Amer. 63: 1273. Abstract.

Lowman, F. G. 1958. Radionuclides in plankton near the Marshall Islands, 1956. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-54.

Lowman, F. G., R. F. Palumbo, and D. J. South. 1957. The occurrence and distribution of radioactive non-fission products in plants and animals of the Pacific proving ground. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-51.

Mao, H. and K. Yoshida. 1954. Physical oceanography in the Marshall Islands area. Geol. Sur. Prof. Paper 260-R.

Munk, W. H. and M. C. Sargent. 1954. Adjustment of Bikini atoll to ocean waves. Bikini and Nearby Atolls, Part 2. Geol. Sur. Prof. Paper 260-B, C, D.

Palumbo, R. F. 1955. The uptake of iodine-131 by the red alga *Asparagopsis taxiformis*. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-44.

Palumbo, R. F. and F. G. Lowman. 1958. The occurrence of Antimony-125, Europium-155, Iron-55, and other radionuclides in Rongelap atoll soil. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-56.

Robinson, M. K. 1954. Sea temperature in the Marshall Islands area, Bikini and nearby atolls, Part 2. Geol. Sur. Prof. Paper 260, B, C, D.

Schultz, L. P. et al. 1953. Fishes of the Marshall and Marianas Islands. 1, Bull. 202. Smithsonian Institute, U. S. Natl. Mus.

Seymour, A. H. et al. 1957. Survey of radioactivity in the sea and in pelagic marine life west of the Marshall Islands, September 1-20, 1956. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-47.

St. John, H. 1949. Report on botanical studies on Eniwetok atoll. U. S. Atomic Energy Commission Donaldson Expedition.

Taylor, W. R. 1950. Plants of Bikini and other northern Marshall Islands, Univ. of Michigan Press, Ann Arbor.

Tracey, J. I. et al. 1948. Reefs of Bikini, Marshall Islands. Bull. of the Geol. Soc. of America 59: 861-78.

Von Arx, W. S. 1954. Circulation systems of Bikini and Rongelap Lagoons. Bikini and nearby atolls, Part 2. Geol. Sur. Prof. Paper 260-B, C, D.

Welander, A. D. 1957. Radioactivity in the reef fishes of Belle Island, Eniwetok atoll, April 1954 to November 1955. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-49.

Welander, A. D. 1958. Radiobiological Studies of the fish collected at Rongelap and Ailinginae atolls, July 1957. Off. Tech. Services, U. S. Dept. Comm. AEC Report UWFL-55.

ACCUMULATION OF RADIOACTIVE POLLUTANTS BY MARINE ORGANISMS AND ITS RELATION TO FISHERIES

Walter A. Chipman, Chief - Radiobiological Investigations
U. S. Bureau of Commercial Fisheries, Beaufort, North Carolina

There are many things to consider in studies of the effects of pollution with atomic materials on our fisheries. One needs to know the character of the wastes, areas of possible contamination, characteristics of the receiving waters, factors of dilution and dispersion, and the living organisms in areas that might be affected. There is then the problem of accumulation and retention of components of radioactive pollutants by marine fishery organisms and their foods. To relate these to the problem, it is necessary to have knowledge of the details of their biology and ecology, practices of the fishing industry, technological processing of fishery products, and fishery economics and marketing.

An accumulation of radioactive materials in fish and shellfish is of importance as it affects man. There is considerable worry that radioactive contaminants may reach man in high concentrations through utilization of seafoods and marine products of commerce. There is also concern that the availability of seafoods may be decreased from changes in populations of fish and shellfish brought about by radiation injury.

Possible damage to our seafood resources from pollution with atomic materials is a field of interest to the Bureau of Commercial Fisheries. Contamination of seafoods with radioactive pollutants is also of concern for it is the responsibility of the Bureau to assist and advise the fishing industry in obtaining marketable seafoods and to work with other agencies of the Government in the selection of standards of seafood quality and the prevention of harmful pollution.

To find answers to some of these problems, the Bureau of Commercial Fisheries, through the cooperation of the Atomic Energy Commission, is conducting studies at its laboratory at Beaufort, North Carolina. This laboratory is

well situated to consider a number of the important fisheries of the Atlantic Coast. It is so located that estuarine environments, which play a great part in Atlantic Coast fisheries, can be studied. The results of some of the studies have been published and others are soon to appear. General discussions of the findings on accumulation of radionuclides by fishery organisms have been given by Chipman (1958, 1959).

Artificially - produced radioactive materials may be present in marine environments as a result of a number of different activities of man. They may be introduced either through accident or intentional disposal of wastes. Those important to fisheries include fall-out material from nuclear weapons, effluents from different atomic industries and from reactors. Of great concern is the possible contamination of fishing areas from ship reactors. We are thus interested in fission products and radionuclides present as metal corrosion products of reactor cooling systems.

Although all such wastes have the common characteristic of being radioactive, they differ greatly in almost every other respect. Present are radioisotopes of chemical elements in specific chemical and physical form. When added to sea water, they may change and be present in much different chemical or physical form. Questions arise immediately as to their distribution and fate in a marine environment and their availability for uptake by fishery organisms.

Like other marine life, fish and shellfish often are able to take up radioactive contaminants of the water. If available in proper form, they enter the bodies of these organisms following the usual pathways for the particular element. With very few exceptions, radionuclides enter into the various metabolisms of the element and follow the normal pathways of its excretion. Since elements are often concentrated

in the body in specific tissues and organs, their radionuclides are similarly concentrated.

We may consider briefly a few points about biological accumulation and concentration of radionuclides. In accumulation we are concerned with changes in the isotopic composition of an element within a tissue. This means changes in the ratio of the number of radioactive atoms to the total number of atoms present, commonly referred to as the specific activity of the radionuclide. With unequal specific activities between the tissues and the outside environment, passage of the element into the organism, or loss from the organism, will tend to bring about an equilibrium in specific activity wherever the element is present. These rates may be slow or fast, depending on the metabolism of the particular element. With like specific activities at equilibrium, we still may have differences in concentrations of the radionuclide between the tissues or the organism and its environment. This results from differences in concentrations of the total element.

In studies of the radiobiology of fishery organisms, we may wish to know the maximum possible concentration for a radionuclide. If we know the concentration of the element within the body, and also the specific activity of the radionuclide of the element taken into the body, we can calculate, for equilibrium conditions, the concentration of radionuclide that will be present. It is important that the specific activity of the radionuclide entering be considered on the basis of total element taken in from all sources. It is unfortunate, however, that in most situations of pollution we are dealing with uneven and changing specific activities. We are forced to deal with changing concentrations.

We need consider what organisms constitute our fisheries. These may be grouped into the general categories of molluscan shellfish, crustacean shellfish, and teleost fishes of many species. All are very unlike in body structure, body composition, mode of life, life history, geographical distribution, habitat, and response to factors of their environment. It is indeed a great task to consider accumulation of radionuclides and radiation damage for such a large and varied group of organisms, particularly when pollution situations may be quite different in character, duration, and extent. However, important fisheries are limited in species taken and generally are located in small geographical areas.

The list of some of the more important fisheries of the Atlantic Coast in Table 1 demonstrates these points. By selection of fisheries for study in relation to their importance, we can narrow our field of work. We are then confronted with a particular biological pattern and mode of life for each fishery selected.

Table 1 is arranged in order of the money value of the catch. This may give a concept of the economic loss that would result from radiation injury to organisms of a fishery. However, a consideration of the number of men and vessels affected may alter the story. It also does not give a concept of the loss of a source of protein food from damage to a fishery.

We may regroup the fisheries listed in Table 1 to show their order in poundage landed. The list thus arranged is given in Table 2. Except for the menhaden and others entering industrial fisheries, such a list may indicate their value as food for man. However, differences exist in the importance of certain fisheries in particular areas. For example, the mullet fishery of the South Atlantic is important only in certain market areas.

We may now consider phases of biological accumulation of radioactive materials. There are a number of general principles of biological accumulation that apply to fishery organisms. However, we must further consider how these fit the biology of a particular organism and the fishing practices of a fishery. We can never obtain quantitative answers as to hazardous levels of pollution without this detailed information.

One general consideration of importance is the availability of radioactive materials for uptake by fishery organisms. Sea water, although having elements present in ionic form, is a suspension of particles of many sizes. These are inorganic and organic; living and non-living. Many of the radionuclides added to sea water become associated with the particles present, including living phytoplankton cells. We have found nearly all the fission product radionuclides, and also those of the trace metals, associated with marine plankton cells when added to sea water cultures. Even the rare earth radionuclide, cerium-144, which was chiefly present as particles, was associated with these cells in great amount (Rice and Willis, 1959).

Table 1. Important Fisheries of the Atlantic Coast in Order of Value^{1/}

Common name	Scientific name	Area of greatest catches	Atlantic Coast landings 1956
			Thousands of dollars
Oyster	<i>Crassostrea virginica</i>	Chesapeake Bay	24,984
Menhaden	<i>Brevoortia tyrannus</i>	Middle Atlantic	20,021
Northern lobster	<i>Homarus americanus</i>	Maine	11,908
Sea scallop	<i>Placopecten magellanicus</i>	Massachusetts	10,822
Haddock	<i>Melanogrammus aeglefinus</i>	Massachusetts	9,587
Shrimp	{ <i>Penaeus setiferus</i>	South Atlantic	7,825
	<i>Penaeus aztecus</i>		
	<i>Penaeus duorarum</i>		
Hard clam	<i>Venus mercenaria</i>	Middle Atlantic	6,044
Ocean perch	<i>Sebastes marinus</i>	Massachusetts	5,723
Blue crab	<i>Callinectes sapidus</i>	Chesapeake Bay	5,640
Fluke	<i>Paralichthys dentatus</i>	Middle Atlantic	3,654
Sea herring	<i>Clupea harengus</i>	Maine	2,409
Soft clam	<i>Mya arenaria</i>	Maine	2,349
Cod	<i>Gadus callarias</i>	Massachusetts	2,225
Scup	<i>Stenotomus versicolor</i>	Middle Atlantic	1,994
Surf clam	<i>Spisula solidissima</i>	New Jersey	1,782
Whiting	{ <i>Merluccius bilinearis</i>	Massachusetts	1,683
	<i>Merluccius albidus</i>		
Blackback flounder	<i>Pseudopleuronectes americanus</i>	New England	1,529
Yellowtail flounder	<i>Limanda ferruginea</i>	Massachusetts	1,481
Croaker	<i>Micropogon undulatus</i>	Chesapeake Bay	1,363
Shad	<i>Alosa sapidissima</i>	Chesapeake Bay	1,282
Sea bass	<i>Centropristes striatus</i>	N. J. and Virginia	1,169
Striped bass	<i>Roccus saxatilis</i>	Chesapeake Bay	973
Bay scallop	<i>Pecten irradians</i>	Mass. to N. J.	922
Butterfish	<i>Poronotus triacanthus</i>	Rhode Island	870
Sea trout	<i>Cynoscion regalis</i>	N. J. to N. C.	793
Pollack	<i>Pollachius virens</i>	Massachusetts	702
Alewife	<i>Alosa pseudoharengus</i>	Chesapeake Bay	672
Spot	<i>Leiostomus xanthurus</i>	Chesapeake Bay	592
Gray sole	<i>Glyptocephalus cynoglossus</i>	Massachusetts	558
Dab	<i>Hippoglossoides platessoides</i>	New England	555
Mullet	{ <i>Mugil cephalus</i>	South Atlantic	546
	<i>Mugil curema</i>		
Mackerel	<i>Scomber scombrus</i>	New England	485
Spotted sea trout	<i>Cynoscion nebulosus</i>	Florida	482
Bluefish	<i>Pomatomus saltatrix</i>	N. J. and Florida	427

Although there are a number of important radionuclides which may be taken up by marine animals directly from the water, it is necessary to consider here the importance of particles in the sea in passing elements to fishery organisms. As you all know, in the sea the primary food organisms, the phytoplankton, are almost

exclusively of minute size. Particle filtration by small marine animals is of extreme importance in passing food elements through the complex food-web patterns of most fishes.

In research studies of the accumulation of radionuclides by fishery organisms we are thus

^{1/} Source: Fishery Statistics for 1956. U. S. Fish and Wildlife Service.

Table 2. Important Fisheries of the Atlantic Coast in Order of Catch^{1/}

Common name	Scientific name	Area of greatest catches	Atlantic Coast landings 1956
			Thousands of pounds
Menhaden	<i>Brevoortia tyrannus</i>	Middle Atlantic	1,537,403
Haddock	<i>Melanogrammus aeglefinus</i>	Massachusetts	152,246
Ocean perch	<i>Sebastes marinus</i>	Massachusetts	151,113
Sea herring	<i>Clupea harengus</i>	Maine	147,901
Whiting	{ <i>Merluccius bilinearis</i> <i>Merluccius albidus</i> }	Massachusetts	93,923
Blue crab	<i>Callinectes sapidus</i>	Chesapeake Bay	81,701
Alewife	<i>Alosa pseudoharengus</i>	Chesapeake Bay	53,517
Oyster	<i>Crassostrea virginica</i>	Chesapeake Bay	49,692
Scup	<i>Stenotomus versicolor</i>	Middle Atlantic	36,266
Cod	<i>Gadus callarias</i>	Massachusetts	35,127
Northern lobster	<i>Homarus americanus</i>	Maine	26,520
Shrimp	{ <i>Penaeus setiferus</i> <i>Penaeus aztecus</i> <i>Penaeus duorarum</i> }	South Atlantic	25,536
Pollack	<i>Pollachius virens</i>	Massachusetts	23,023
Fluke	<i>Paralichthys dentatus</i>	Middle Atlantic	22,675
Sea scallop	<i>Placopecten magellanicus</i>	Massachusetts	20,066
Croaker	<i>Micropogon undulatus</i>	Chesapeake Bay	16,562
Surf clam	<i>Spisula solidissima</i>	New Jersey	15,976
Yellowtail flounder	<i>Limanda ferruginea</i>	Massachusetts	14,643
Hard clam	<i>Venus mercenaria</i>	Middle Atlantic	14,251
Blackback flounder	<i>Pseudopleuronectes americanus</i>	New England	14,233
Sea bass	<i>Centropristes striatus</i>	N. J. and Virginia	11,689
Spot	<i>Leiostomus xanthurus</i>	Chesapeake Bay	11,036
Shad	<i>Alosa sapidissima</i>	Chesapeake Bay	9,672
Butterfish	<i>Poronotus triacanthus</i>	Rhode Island	9,319
Sea trout	<i>Cynoscion regalis</i>	N. J. to N. C.	8,779
Mullet	{ <i>Mugil cephalus</i> <i>Mugil curema</i> }	South Atlantic	8,584
White hake	<i>Urophycis tenuis</i>	New England	6,466
Soft clam	<i>Mya arenaria</i>	Maine	6,116
Dab	<i>Hippoglossoides platessoides</i>	New England	5,908
Gray sole	<i>Glyptocephalus cynoglossus</i>	Massachusetts	5,293
Spanish mackerel	<i>Scomberomorus maculatus</i>	Florida	4,941
Striped bass	<i>Morone saxatilis</i>	Chesapeake Bay	4,480
King whiting	<i>Menticirrhus americanus</i>	South Atlantic	4,065

compelled to study the accumulation of radioactive materials by phytoplankton and by various zooplankton forms. We must consider particular food webs related to a fishery.

Generally, passage of the radionuclides associated with particles through food webs to our

higher fishes and to man depends on absorption of the radionuclides from the digestive tract and accumulation in the body of each of the different organisms. However, molluscan shellfish are filter-feeding forms and are able to concentrate particles from large volumes of water. If continuously available, radioactive particles may

^{1/} Source: Fishery Statistics for 1956. U. S. Fish and Wildlife Service.

accumulate in filtering mechanisms, on body surfaces, and within the digestive tract. These may give a high radioactivity even though the radionuclides responsible for the radioactivity are poorly absorbed and not concentrated within the tissues. We have measured rather high concentrations of cerium-144, ruthenium-106, and others when the entire soft tissues of shellfish were sampled. The greater part of the radioactivity was due to association of particles with body surfaces and their presence in the organs and structures connected with the digestive tract.

It is the concentration level of a radionuclide in seafood organisms that determines its hazard to man and its ability to cause radiation damage. Consequently, we are concerned with determining concentrations in different organs and tissues. In studies of the body distribution of radionuclides for consideration of radiation damage, we need search for radiation-sensitive critical tissues. Passage of concentrations of radioactive materials to man, however, involves only those tissues utilized as a seafood. For the most part, this means concentrations in muscle tissue. However, there are a number of important exceptions.

Of great importance is the fact that the entire soft tissues of oysters and clams are utilized. These shellfish are known to contain extremely high concentrations of certain metals and can be an important source of the radionuclides of those trace metals present as corrosion products (Chipman, *et al.*, 1958). Other seafoods may be less important if only concentrations in muscle tissue need be considered. Cesium-137, an important fission product, is concentrated in muscles. We have found that clams concentrate cesium-137 to a greater extent than do oysters, which is in agreement with the difference in their body structure as regards muscle tissue. For this radionuclide, the most hazardous of the molluscan shellfish is the scallop, since only the adductor muscle is eaten.

Because of the inclusion of clarified structures in the marketing of some seafoods, such as the marketing of sea herring as Maine sardines, these products can be an important source of strontium-90 to man. In fact, sardines are considered as important as certain dairy products as a source of calcium and strontium.

Because of the nature of the problem of the effects of pollution of marine environments with

radioactive materials on fisheries, we must consider the dynamic phases of accumulation and retention of radionuclides by fishery organisms. In this pollution problem, we are apt to be dealing with localized areas of pollution, in which the amount and times of addition of the pollutant may vary. These changes alter the concentration of radioactive contaminants in the organisms of an area. Furthermore, most fishery organisms move and migrate and can pass into and out of polluted areas. This results in changes in the radioactivity of their tissues.

It is conceivable that estuaries are likely to be areas in which the concentrations of radioactive pollutants will be higher than in offshore areas. For the important fisheries of the Atlantic coast, inshore areas, and particularly the estuaries, are of extreme importance. Some species, such as certain shellfish, are limited to estuarine waters. Some fishes are anadromous and enter fresh waters to spawn. Inshore fishes move offshore in certain seasons. Some offshore fishes spend their early lives in nursery areas within estuaries.

In the case of estuarine species, differences in concentration of pollutants within sections of an estuary can be important. The edible blue crab has a migration pattern within estuaries in which the females congregate in the more saline waters for the hatching and release of zoea while the males remain in areas of fresher water. Although adult oysters may be considered sedentary, they are moved about by oystermen in transplanting operations.

In view of the facts that pollution of marine waters may be localized or transitory and fishery organisms move about, we in fisheries research have concerned ourselves with measurements of the rates of accumulation and loss of radionuclides and the effects of season, temperature, salinity, growth, etc., on these rates. These are considered in relation to the biology of our seafood organisms and to fishing practices. All are important in attempting to evaluate pollution in reference to concentrations of radioactive materials in the tissues of fish and shellfish at the time of capture or harvesting, or at critical times in their life histories.

We may now turn to a consideration of radiation damage. It is generally agreed that any ionizing radiation may be injurious to living tissues. However, there are small amounts of

radioactive materials in living things and some artificially-produced radionuclides are being incorporated. There arises the question of accumulation levels above which serious injury will occur.

Based on the best available information as to the effects of ionizing radiation on human tissues, permissible body burdens of many radionuclides have been established (National Bureau of Standards, 1953). With consideration of the amount of water consumed and of body accumulation, physical decay of the isotope, retention time in the body, the maximum permissible concentration (MPC) for a particular radionuclide in drinking water has been designated. The amounts present in foods ingested by man have likewise been limited to prevent the building up of an excessive body burden.

It is often stated that waters polluted with radioactive materials contain various radionuclides at concentrations well below their MPC values for drinking water. One is led to believe that this also means that these concentrations are also safe levels for aquatic life. This does not necessarily hold true. Aquatic organisms differ from humans in elemental composition, body structure and function, and mode of life. Actually we do not know permissible body burdens for various radionuclides for aquatic life. We are not in a position to state permissible levels of concentration in the water in which they live nor in the foods which they ingest.

To establish such values we need yet to know the organs and tissues of these fishery organisms that are critically sensitive to radiation. These may well be specialized larval structures or tissues. We then need to know the permissible amounts that can be concentrated in these organs and tissues and relate this to the total amount of element present and to the specific activity of the water or food material.

Again, we need information on the MPC value as regards a particular fishery organism. For instance, we know for the grass shrimp, *Palaeomonetes pugio*, concentrations of cesium-137 in the body and in the water which bring about a delay in larval development and which delay or

prevent metamorphosis. Such concentrations, if present in estuaries, might also delay development of blue crab larvae or prevent the change from megalops to crab. Shrimp larvae of the genus, *Penaeus*, however, hatched outside the estuary have completed metamorphosis to the adult form when they enter the nursery grounds of the estuary.

Radiation damage to fishery organisms is important in so far as it changes populations. We are dealing with wild populations in which only the fit survive. For fishery organisms, continuation of the population is usually dependent on the production of great numbers of eggs with only a few of those fertilized reaching maturity. Conditions for survival are often very precise and restrictive. There is evidence, for example, that metamorphosis in the blue crab can take place only within a certain range of salinity. The oyster produces fabulous numbers of eggs. Of those fertilized, only a few continue through elaborate larval stages during which mortality is very great. On reaching a stage for attachment, some find a suitable surface and a large number may attach to a single oyster shell. Because of the need for space, only two or three may survive. Even then predation and disease, or even freshets, take a tremendous toll. Genetic changes resulting from radiation damage may be less serious in such wild populations in which mortalities from other causes are so great. However, there is evidence that the number making up the population for certain fisheries is not great enough to maintain itself at current fishing intensities and overfishing may be a serious matter. It is not unreasonable to think that an added mortality from radiation injury might be critical in a particular fishery.

We have some information on the accumulation of certain radioactive pollutants and can visualize how pollution with these materials might affect our seafood industry or our fisheries. We still lack detailed information for most pollutants and for most of our fisheries. This detailed information is essential in order to arrive at quantitative figures in advance of actual pollution.

REFERENCES

Chipman, Walter A. 1958. Biological accumulation of radioactive materials. Proc. First Annual Texas Conference on Utilization of Atomic Energy, Misc. Publ. Texas Engineering Experiment Station, pp. 36-41.

Chipman, Walter A. 1959. Accumulation of radioactive materials by fishery organisms. Proc. 11th Annual Meeting, Gulf and Caribbean Fisheries Institute (in press).

Chipman, Walter A., Theodore R. Rice, and Thomas J. Price. 1958. Uptake and accumulation of radioactive zinc by marine plankton, fish, and shellfish. Fishery Bull. 135, Fishery Bull. Fish and Wildlife Serv. 58:279-292.

Rice, T.R., and Virginia M. Willis. 1959. Uptake, accumulation and loss of radioactive cerium-144 by marine planktonic algae. Limology and Oceanography 4: (in press).

THE SIGNIFICANCE OF THE UPTAKE OF RADIOISOTOPES BY FRESH-WATER FISHES

Richard F. Foster, Manager - Aquatic Biology Operation, Hanford Laboratories
General Electric Company, Richland, Washington

The uptake of radioactive materials by aquatic organisms is a well recognized process and many measurements of the concentration of isotopes in fish have been made both in the field and in the laboratory. There would appear to be five basic reasons for making such measurements:

1. Research studies in which the objective is to learn more about the movement and distribution of a particular element, compound, or organism in a biological system. The particular system being studied may range in size from sub-cellular to entire communities. Here the isotope serves principally as a tag and we are not interested in the radiation except that it provides the means of detection and quantization.

2. Research studies in which the objective is to learn more about the biological effects of radiation. Again the system under investigation may range in size and complexity from sub-cellular to an entire community. Here the important thing is the radiation exposure to particular sites, and this is affected not only by the concentration of each isotope present but also by the specific location or deposition pattern of the emitter and the physical characteristics of the radiation.

3. Field surveys in which the objective is to determine whether or not organisms have picked up a sufficient quantity of radioactive materials so that they suffer radiation damage.

4. Field surveys in which the objective is to determine whether or not organisms used as food by man are safe for consumption.

5. Field monitoring in which the objective is to follow the bioaccumulation of radioactive materials in the environs of an atomic energy installation, or explosion, over extended periods of time in order to relate the release of nuclides to the environment with the contamination which results.

In practice, it may turn out that a single set of measurements can be used for more than one purpose. For example, samples collected to determine if fish are safe for human consumption may also serve to indicate the magnitude of the exposure to the fish. If continued over long periods, the same samples may provide monitoring of trends. The objectives should be firmly established at the outset, however, and programs which set out only to measure broadly "the radioactivity of organisms" should be avoided.

MEASUREMENT OF RADIOACTIVE CONTAMINANTS IN FISH.

Since this seminar is concerned with "Biological Problems in Water Pollution", emphasis will be placed on the significance of the concentrations of radioisotopes in fish which may result from situations where radioactive materials are, or may be, present as environmental contaminants.

Let us assume that appropriate samples have been collected in the field and these are to be analyzed in the laboratory for radioactive materials. The simplest measurements to make indicate only the amount of radiation emitted from the sample. Dependent upon the type of detector and the way the sample is prepared, the counter may be more or less efficient in measuring the beta or alpha particles or gamma rays which are emitted by the disintegrating atoms.

Not all of the counts recorded by the measuring instrument will have originated from artificially radioactive isotopes in the sample. In addition to the background which is tallied by the instrument, whether a sample is present or not, naturally radioactive isotopes contained in biological specimens will contribute a significant count. Most of the natural activity in fish

results from a radioactive isotope of potassium, K^{40} , which is mixed with stable potassium in the ratio of 1:10,000. The K^{40} in large fish, with a potassium content of about 0.3 percent, contributes about 6 disintegrations per minute per gram (Folsom and Harley, 1957). In different units, this amounts to about $3 \times 10^{-6} \mu\text{c/g}$. The measured amount of natural radioactivity in Columbia River fish upstream from the Hanford reactors is in good agreement with this value (Davis, Watson, and Palmiter, 1956) (Robeck, Henderson, and Palange, 1954).

If the counting rate, or other considerations, indicate that artificially radioactive materials are present, the significance of the contamination must be appraised. No longer is this a simple matter of measuring the number of disintegrating atoms per minute since the evaluation must be based on a knowledge of the kinds of isotopes present. Identification is necessary from the standpoints of permissible limits for both human consumption and exposure of the fish. Often it involves elaborate radiochemical procedures, but in the last few years advances in instrumental analysis have greatly facilitated identification and measurement, particularly for the gamma emitters.

PERMISSIBLE LIMITS FOR HUMAN CONSUMPTION

Recommendations have been made for the maximum permissible internal concentration of radioisotopes in the human by such groups as the International Commission on Radiological Protection (1955) and the National Committee on Radiation Protection and Measurement (1953). The philosophies behind these recommendations and the methods of calculation are considerably beyond the scope of this discussion, but in a broad sense they are based on radiation dose rates to "critical" organs where specific isotopes are expected to accumulate or, in the case of isotopes which go principally to the bone, by comparison to the toxicity of radium. Although the basic limit is the isotope burden in the body (or organ), usually the most practical means of controlling the amount deposited is to place limits on the rate at which the isotopes enter the body, either by ingestion or inhalation. In order to arrive at permissible rates of ingestion, information on the fraction of the ingested dose which reaches the critical organ, and retention of the radioisotope in the organ must be taken

into account. Once the permissible rate of ingestion has been established, it is a matter of simple arithmetic to compute a permissible concentration for drinking water if one assumes a standard rate of water intake (2.2 liters per day) and excludes intake of the isotope from other sources. Maximum permissible concentrations (MPC's) for radioisotopes in drinking water are included in recommendations of the ICRP (1955) and NCRP (1953) and these values are, at the present time, widely accepted as the authoritative limits. Owing to the uncertainties involved at each of the several steps required in arriving at the MPC's, the validity of the limits must be accepted with some reservations (Thompson, Parker, and Kornberg, 1955). On the other hand, the MPC's for many of the isotopes are undoubtedly as good, if not better, than some limits for other criteria of water quality in use today.

No limits have yet been developed which relate specifically to the permissible concentration of radioisotopes in fish. While this means that there is no fixed standard of reference with which to compare the concentration of isotope observed in a sample of fish, it does not imply that such a set of limits would be desirable. Indeed, in those situations where substantial quantities of radioactive materials are taken up by fish, significant amounts of the isotopes are apt to be present in other components of the environment which may also contribute to the radiation exposure of local inhabitants. The situation calls not so much for a fixed set of reference values as it does a comprehensive evaluation of the total exposure to individuals from all significant sources. The dietary habits of the people are an important aspect of this evaluation.

Although the limits for internally deposited isotopes have been stated in terms of MPC's for drinking water, these values can be used as a guide for the permissible rate of ingestion of radioisotopes contained in foodstuffs as well. The usual practice is to recover the permissible ingestion rate, expressed in $\mu\text{c/day}$, by multiplying the MPC for drinking water by the standard consumption rate for water (2,200 cc/day). It follows in the application of such limits to fish, that one must consider not only the concentration of the isotope in the edible parts, but also the quantity which is apt to be consumed in some appropriate interval of time. For areas where locally caught fish make up a consistent

Table 1. Comparison of permissible levels and exposure rates

Isotope	Half life	MPC		Rads/week to fish	
		Water ^{1/} $\mu\text{c/cc}$	Fish ^{2/} $\mu\text{c/g}$	Internal ^{3/}	External ^{4/}
Na ²⁴	15.0 h	8×10^{-4}	0.1	40	1
Ca ⁴⁵	160.0 d	2×10^{-3}	0.3	8	(1×10^{-2})
Zn ⁶⁵	245.0 d	2×10^{-4}	3×10^{-2}	1	4×10^{-2}
p ³²	14.5 d	2×10^{-5}	3×10^{-3}	0.8	(2×10^{-3})
Co ⁶⁰	5.2 y	4×10^{-5}	6×10^{-3}	0.7	3×10^{-2}
I ¹³¹	8.0 d	6×10^{-6}	9×10^{-4}	7×10^{-2}	7×10^{-4}
Sr ⁹⁰ +Y ⁹⁰	28.0 y	8×10^{-8}	1×10^{-5}	2×10^{-3}	(1×10^{-5})

and major part of the diet, the concentration of radioisotopes in edible parts of the fish would have to be held to a much lower level than in areas where there is but infrequent and casual consumption.

The National Committee on Radiation Protection and Measurements (1958) has recommended that: "The maximum permissible average body burden of radionuclides in persons outside of the controlled area and attributable to the operations within the controlled area shall not exceed one-tenth of that for radiation workers. . . . This will normally entail control of the average concentrations in air or water at the point of intake, or rate of intake to the body in foodstuffs, to levels not exceeding one-tenth of the maximum permissible concentrations allowed in air, water, and foodstuffs for occupational exposure. The body burden and concentrations of radionuclides may be averaged over periods up to one year.

"The maximum permissible dose and the maximum permissible concentrations of radionu-

clides as recommended above are primarily for the purpose of making the average dose to the whole population as low as reasonably possible, and not because of specific injury to the individual."

Since uptake, deposition, retention, and radiation characteristics differ from one isotope to another, the permissible rates of intake are also quite different for various isotopes. This is apparent from tabulations of the MPC's recommended for drinking water (ICRP 1955) which range from $0.2 \mu\text{c/cc}$ for tritium to $8 \times 10^{-7} \mu\text{c/cc}$ for Sr⁹⁰+Y⁹⁰ (beta emitters) and 4×10^{-8} for Ra²²⁶ (an alpha emitter). The MPC for Sr⁹⁰+Y⁹⁰ in drinking water is equivalent to a permissible ingestion rate of $1 \times 10^{-2} \mu\text{c}$ per week under controlled conditions or an average of $1 \times 10^{-3} \mu\text{c}$ per week for persons outside of controlled areas. This total amount of Sr⁹⁰+Y⁹⁰ might then be contained in the foodstuffs and drinking water ingested by an average person each week. If the sole source of the isotope was fish and an average of 100 grams of such fish were eaten by a person each

^{1/} Drinking water for populations outside of controlled areas.

^{2/} For edible parts of the fish consumed at the rate of 100 g/week.

^{3/} For isotope uniformly deposited in fish at MPC level and fish of about 7 cm thickness.

^{4/} For fish of about 7 cm thickness swimming in water at the MPC for drinking purposes. () Values in parentheses are for dose at surface since only B particles are involved.

week throughout the year^{1/} the maximum permissible concentration in the edible parts of the fish would be $1 \times 10^{-5} \mu\text{c/g}$. A value applicable to a specific situation might be lower or higher than this dependent upon the actual quantity of fish consumed and the Sr^{90} content of other foods included in the diet.

If we assume that $1 \times 10^{-5} \mu\text{c Sr}^{90} + \text{Y}^{90}/\text{g}$ of fish is applicable to a particular situation, the measurement of this amount must be considered. This concentration would yield approximately 20 disintegrations per minute per gram which is only about three times the number produced by the natural K^{40} mentioned earlier.

The above example, based on Sr^{90} , represents about the worst possible case. Applicable limits for most other isotopes will be several orders of magnitude greater than this and measurement will be much simpler. Nevertheless, this example should emphasize the need for identification of the emitter as a primary step in evaluating the significance of the radioactivity.

Where radioactive material has entered the water from an atomic energy operation it is probable that not one but several different isotopes will be present. While the significance of each of the isotopes must be evaluated separately, the biological effect which each produces is not independent of that produced by the others. Thus, where a mixture of isotopes is present, the permissible concentration of each one will be lowered in proportion to the fraction of the MPC used up by all others. Different isotopes may, however, deposit in different parts of the body so that the effects produced are not entirely additive. Healy, et al (1958) have described the method of summing exposures from different isotopes and different sources which is currently used for estimating the dose rate to people in the environs of the Hanford Plant.

PERMISSIBLE LIMITS FOR FISH

Although a number of tests have been run to follow the uptake and deposition of several isotopes in both marine and fresh-water fish (Boroughs, Chipman, and Rice, 1957) (Krumholz

and Foster, 1957), there is little direct information on the concentrations of deposited isotopes which produce significant radiation damage to fish. We do know that the whole body dose (usually X-rays) which kills half of the fish is on the order of 1000 roentgens - roughly twice that for man (Donaldson and Foster, 1957). This is only a very crude index to the exposure which the fish could tolerate from isotopes deposited heterogeneously throughout the body and which continue to irradiate tissues of varying sensitivity over long periods of time.

Some information is available on the concentration of radiophosphorus in fish which is tolerable (Watson, George, and Hackett, 1958). Trout fed $0.06 \mu\text{c P}^{32}$ per gram of body weight five days a week for a period of about six months maintained a concentration of about $0.25 \mu\text{c P}^{32}/\text{g}$ of muscle and $1.5 \mu\text{c/g}$ of bone. At this level the trout were slightly affected by the radiation; the most apparent effect was a depression in growth rate after 17 weeks at which time the cumulative dose to the bone was on the order of 6000 rads and to the muscle about 800 rads. Trout which received ten times as much isotope in their diet all died, but those which received one-tenth as much were apparently unaffected.

Whether similar concentrations of other isotopes will be more or less damaging remains to be seen. Ultimately, through a series of similar long-term tests, it should be possible to establish maximum permissible concentrations for the more important isotopes in fish. Such limits should not be fraught with the uncertainties which must accompany recommendations for the MPC's for drinking water for man since experimental evidence can be obtained directly on the species involved and the risk factor considerations are different. One must bear in mind, however, that some radioactive materials which are ingested by the fish will not readily pass through the walls of the gastrointestinal tract. The effect of their radiation will, then, be principally on the GI tract as the contaminated food bolus moves through the fish. Under such circumstances the maximum permissible concentration would need to be applied to the feces or to the food materials of the fish rather than to some fish tissue.

^{1/} This example is based on the eating habits of rural families in the U. S. according to statistics of the U. S. Department of Agriculture (1955). One hundred grams per week approximates the consumption rate of fresh and frozen fish, such as might be obtained from fresh-water lakes and streams, and does not include canned or commercially packed fish of marine origin.

COMPARISON OF LIMITS

Within the present framework of the recommended limits on rates of ingestion of isotopes for human populations, we can estimate permissible levels for radioactive materials in edible fish products. This is possible provided each situation is examined in detail for all significant sources of exposure, the dietary habits of the population are known within reasonable limits, and the isotopes are identified. For purposes of illustration, MPC's were computed for a few isotopes of quite different radioactive and biological properties using the assumptions that fish was the only source of the isotope and that the rate of consumption was 100 grams per week. The results are shown in Table 1.

An adequate basis for estimating permissible levels for fish is not yet available. Radiation exposure rates which result from isotopes deposited in small organisms are extremely difficult to compute with the desired degree of accuracy. This is because the isotope is not uniformly distributed throughout the body, or even throughout a single organ or tissue, because one organ contributes to the dose of an adjacent organ, because the concentration of the isotope may change with time, because body structures have irregular shapes, and because of complexities associated with the energy released. Some approximation of the over-all dose can be obtained without great difficulty, however, if one is willing to oversimplify. Again for the purposes of illustration, a general dose rate to the fish has been calculated for the isotopes listed in Table 1. In making these computations, it was assumed that the isotope was uniformly distributed throughout the entire fish at the concentration specified for the MPC if 100 grams were to be eaten each week, and that the fish was about 7 cm thick. An estimation of the dose rate which the fish might receive from

the surrounding water was also made. In this case the chosen concentration of the isotope in the water was the MPC for drinking water. For those isotopes which do not emit gamma radiation, the external dose will be significant only at the surface of the fish.

The magnitude of the exposures listed in the table would seem to indicate that the dose from outside the fish is relatively unimportant, but that for some isotopes which are retained inside the fish at permissible concentrations, the exposure may be significant. An interesting comparison can be made with P^{32} , however. Watson *et al* (1958) found that trout which contained about $2.5 \times 10^{-2} \mu\text{C } P^{32}/\text{g}$ of muscle suffered no detectable somatic damage. This level is about ten times higher than the MPC shown in Table 1 for use of the fish as food. It would appear, then, that if the concentration of P^{32} in the fish is sufficiently low to permit their regular use as food, it is unlikely that the fish themselves will be significantly affected by the radiation.

CONCLUSION

Measurement of the amount of radioactive material taken up by fish from their environment does not complete the task of appraising the magnitude of the problem. In order to evaluate the condition adequately, the results must be compared with appropriate limits. Such limits may, however, differ from one set of conditions to another. The basis for the limits may be the use of fish as food, or radiation damage to the fish themselves. For different isotopes, for different physical-chemical states, and for different biological conditions, the limiting case may change from one basis to another. The significance of the radioactivity measured in fish can, therefore, be determined only after a rather comprehensive evaluation of multiple factors.

REFERENCES

- Boroughs, H., W. A. Chipman, and T. R. Rice. 1957. Laboratory experiments on the uptake, accumulation, and loss of radionuclides by marine organisms. Chapter 8 of "The Effects of Atomic Radiation on Oceanography and Fisheries". National Academy of Sciences - National Research Council, Publication 551: 80-87.
- Davis, J. J., D. G. Watson, and C. C. Palmiter. 1956. Radiobiological studies of the Columbia River through December, 1955. Atomic Energy Commission Document HW-36074. (CLASSIFIED).
- Donaldson, L. R., and R. F. Foster. 1957. Effects of radiation on aquatic organisms. Chapter 10 of "The Effects of Atomic Radiation on Oceanography and Fisheries". National Academy of Sciences - National Research Council, Publication 551: 96-102.
- Folsom, T. R., and J. H. Harley. 1957. Comparison of some natural radiations received by selected organisms. Chapter 2 of "The Effects of Atomic Radiation on Oceanography and Fisheries". National Academy of Sciences - National Research Council, Publication 551: 28-33.

Healy, J. W., B. V. Andersen, H. V. Clukey, and J. K. Soldat. 1958. Radiation exposure to people in the environs of a major production atomic energy plant. Second International Conference on the Peaceful Uses of Atomic Energy, Paper No. 743.

International Commission on Radiological Protection. 1955. Recommendations of the International Commission on Radiological Protection (Revised December 1, 1954). British Journal Radiology, Supplement No. 6.

Krumholz, L. A., and R. F. Foster. 1957. Accumulation and retention of radioactivity from fission products and other radio-materials by fresh-water organisms. Chapter 9 of "The Effects of Atomic Radiation on Oceanography and Fisheries". National Academy of Science - National Research Council, Publication 551: 88-95.

National Committee on Radiation Protection and Measurements. 1958. Maximum permissible radiation exposures to man. Radiology 71: 263-266.

National Committee on Radiological Protection, Subcommittee on Permissible Internal Dose. 1953. Maximum permissible amounts of radioisotopes in the human body and maximum

permissible concentrations in air and water. U.S. Department of Commerce, National Bureau of Standards, Handbook 52, Washington, D.C.

Robeck, G. G., C. Henderson and R. C. Palange. 1954. Water quality studies on the Columbia River. U.S. Department of Health, Education, and Welfare, Public Health Service, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Thompson, R. C., H. M. Parker, and H. A. Kornberg. 1955. Validity of maximum permissible standards for internal exposure. Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, 13: 201-204, Paper No. 245.

U.S. Department of Agriculture. 1956. Food consumption of households in the United States. Household Food Consumption Survey 1955, Report No. 1. U.S. Government Printing Office, Washington, D.C.

Watson, D. G., L. A. George, and P. L. Hackett. 1958. Effects of chronic feeding of phosphorus-32 on rainbow trout. Paper presented at the International Congress on Radiation Research, Burlington, Vermont, August 1958. (Not yet published).

INVESTIGATION OF THE EFFECTS OF RADIOACTIVE MATERIAL ON AQUATIC LIFE IN CANADA

Ivan L. Ophel - Environmental Research Branch, Atomic Energy of Canada Ltd.,
Chalk River, Ontario. Canada.

ABSTRACT

At the Canadian Atomic Energy Project the Environmental Research Branch of the Atomic Energy of Canada Ltd. has been investigating for a number of years the effects of dispersing radioactive wastes into fresh waters. Wastes containing very low concentrations of radioisotopes are being diluted and dispersed in the Ottawa River which flows past the research establishment. In addition, a small lake on the company's property contains radioactive strontium, and provides an opportunity for tracing the path of that radioisotope through the food chains in the lake.

In the Ottawa River the dilution of the radioactive material is so great that the major problem of the investigators is the problem of identifying the radioisotopes found in the collections of water, mud, plants and fish. Some re-concentration by plants and animals does occur, but the only radioactive isotope found in easily detectable amounts in the aquatic animals is the short-lived phosphorus isotope, P³². Radioactive isotopes are carried to the bottom of the river by sediment settling out from the water. This radioactivity does not remain on the bottom, but is dissolved and carried away. After thirteen years of operation

only millicurie amounts of fission products per square mile are found on the river bottom near the Project. Lesser amounts are found downstream.

In Perch Lake much of the radioactive strontium entering the lake has been retained within the lake. Over a three-year period only 30 percent of the Sr⁹⁰ carried into the lake has left it. Much of the retained Sr⁹⁰ is held in the bones of the fish and other animals living in the lake. After three years, concentrations of Sr⁹⁰ in bones of fish and aquatic mammals have reached more than one thousand times that found in the lake water.

Experimental work on the accumulation of long-lived fission products by fish is in progress. Results of experiments with Sr⁹⁰ show that uptake is greatly reduced by the presence of calcium or magnesium in the water, and by low temperatures. Food is not necessary for Sr⁹⁰ uptake by fish. They can accumulate high concentrations by direct absorption through their gills. It is evident that many of the barriers to Sr⁹⁰ transfer that are found in dry-land communities are not present in fresh-water communities.

PROBLEMS RELATED TO DISPOSAL OF RADIOACTIVE WASTES IN ESTUARINE AND COASTAL WATERS

D. W. Pritchard, Director - Chesapeake Bay Institute,
The Johns Hopkins University, Baltimore, Maryland

ABSTRACT

In this paper the general approach to the evaluation of the suitability of any given marine locale as a receiver of nuclear wastes is presented. The starting point for any such evaluation is the allowable radiation dose which the general public may receive without undue risk. Consideration must be given to the routes by which activity may return to man from the marine environment, the processes of concentration of activity from sea water into the food chain, uptake of activity by suspended silt and bottom sedi-

ments, and the physical processes of movement and dispersion.

The application of this general approach to the estuarine and coastal environment is discussed. Emphasis is placed on the present status of knowledge concerning the physical processes of movement and dispersion of a pollutant introduced into estuarine and coastal waters, and to the problem of uptake of activity on suspended silt and bottom sediments.

INTRODUCTION

An unavoidable consequence of the utilization of atomic energy for power production and other peaceful purposes is the production of unwanted fission product wastes. While the major portion of these wastes is now and will be in the future stored in tanks on land, it is difficult if not impossible to avoid the discharge of low level operational wastes to the environment. These operational wastes include leakage from the primary or secondary cooling systems, containing induced activity; laundry wastes; and laboratory wastes. Other papers presented at this seminar will discuss the sources of pollution from the peaceful uses of atomic energy, and hence the matter will not be treated further in this presentation.

The increased utilization of nuclear power will undoubtedly lead to the establishment of power reactors on the shores of estuaries and coastal waters. Nuclear powered ships are a second potential source of radioactive wastes which might be introduced into these marine environments.

Before treating estuarine and coastal environments specifically, it is desirable to describe the general approach to the evaluation of any marine locale as a receiver of nuclear wastes.

GENERAL APPROACH TO THE EVALUATION OF THE SUITABILITY OF A MARINE LOCALE AS A RECEIVER OF NUCLEAR WASTES

The fate of radioactive material introduced into the marine environment is dependent upon the following considerations:

1. The physical and chemical form in which the material occurs at time of introduction, together with any relatively rapid changes in the physical and chemical character of the introduced material which occur when it is brought into contact with sea water. The subsequent dispersion by physical processes and re-concentration by the biota and bottom materials will be greatly affected by the physical and chemical form in which the wastes occur in sea water.

2. Initial mechanical dilution of the wastes by the receiving waters, which will depend upon

Contribution No. 41 of the Chesapeake Bay Institute. This work was supported by the Office of Naval Research, the State of Maryland (Department of Research, and Education), and the Commonwealth of Virginia (Virginia Fisheries Laboratory).

the manner of introduction. Thus a liquid waste will be subject to greater initial mechanical dilution if introduced as a strong jet into the body of the receiving waters, than if introduced as a gently flowing stream on the surface. Large initial mechanical dilution is important in reducing the density difference between the initial contaminated volume and the surrounding receiving waters. This reduction in turn favors subsequent turbulent diffusion.

3. Advection of the waste material away from the source region, and simultaneous turbulent diffusion, which lead to reduced concentrations of the radioactive components in the water.

4. Uptake of the activity onto suspended silt and bottom sediments, which removes some of the radioactive materials from the water, and restricts further dispersion. In deep water such removal would be favorable since material incorporated with the bottom sediments there would be unlikely to return to man's environment. In shallow coastal areas containing bottom living shellfish and bottom feeding commercial fin fish, concentration of radioactivity on the bottom may be unfavorable since these detritus and filter feeders may further concentrate the activity from the bottom material.

5. Concentration of activity by various parts of the biota, including shellfish and fin fish important to man as a source of food. Some important fission products and corrosion products are concentrated by marine organisms by factors of 100 to 10,000 over the concentrations of these isotopes in the water.

The evaluation of the suitability of any particular marine locality as a receiver of nuclear wastes ideally involves the precise, step by step consideration of all factors affecting the possible return of radioactive material to man. The general procedure is the same whether the evaluation concerns: (a) the selection of suitable disposal areas for packaged wastes; (b) the selection of the position of an outfall discharging low level liquid effluent from a chemical processing plant; (c) the consideration of the suitability of a given harbor or harbor approach to receive low level liquid wastes from nuclear powered ships; or (d) the determination of the suitability of the mixed layer of the open ocean to receive wastes from the ion exchange resins on nuclear powered ships. Understanding of

many of the physical and biological processes involved is, however, far from adequate, and further research is recommended to provide a more adequate foundation for the determination of the capacity of any particular marine locale to receive nuclear waste materials without undue risks to man.

Figure 1 presents in schematic form such a step by step procedure. The solid arrows between blocks on the diagram indicate the route taken by the radioactive material in returning to man, while the dashed arrows indicate the reverse course taken in the evaluation. The starting point in the evaluation is man. In order to make any evaluation of the problem at all, some maximum permissible rate of exposure must be adopted. The usual basis for the selection of such a maximum rate would be the national (or international) published statement of the maximum permissible ingestion rate for the various isotopes, for the general population. At the outset it should be recognized that such a maximum permissible rate of exposure is not the most desirable rate. The latter, where technical and economic feasibility allow, should be as close to zero as possible. Thus in making this evaluation, some real, though admittedly extremely slight, risk to the general public is assumed.

Considerable care should be taken in any evaluation that the potential additive effect of exposure to radiation from various sources is given due consideration. The second step in the evaluation is then a consideration of all sources of radiation exposure to the particular segment of the population which would also be potentially affected by the waste disposal operations. On the basis of such consideration a portion of the maximum permissible dose is assigned to sea disposal.

The next step is the consideration of the various routes which the radioactivity can take in reaching man from the marine environment. Here an evaluation of the uses man makes of the marine environment is required. The possible danger of direct radiation, the harvest of seafood, possible contamination of fishing gear and of beach sand are some of the items which should be considered at this stage of the study.

The determination of the maximum permissible concentrations of the various significant isotopes in those parts of the marine environ-

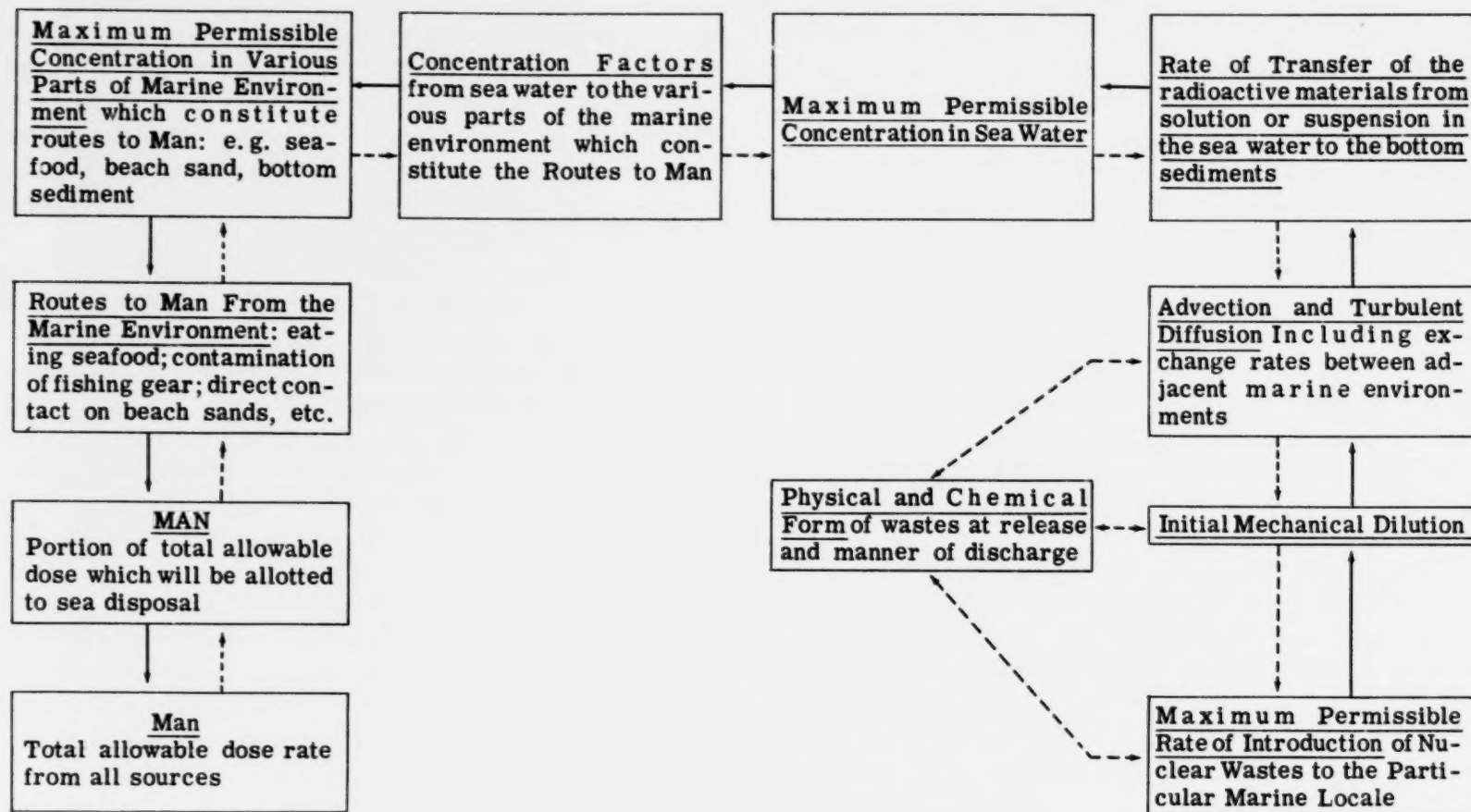


Figure 1. Schematic Presentation of the Step by Step Considerations which Should be made in Evaluating the Suitability of Any Marine Locale as a Receiver of Nuclear Wastes.

ment (seafood, bottom sediments, and shore material) which constitute the routes by which radioactivity may return to man from the sea, then follows as the next step in the process. From a consideration of the known factors by which the biota and the sediment concentrate the various radioactive isotopes from the sea water, it is then possible to arrive at the maximum permissible concentration of the various isotopes in the sea water.

The final steps involve evaluating the changes in the concentration and distribution of radioactivity which may be brought about by

(a) exchange between bottom sediment and suspended or dissolved material in sea water;

(b) advection and turbulent diffusion, both within a given marine environment and between adjacent environments;

(c) initial mechanical dilution, influenced by manner of discharge; and

(d) physical and chemical form of the wastes at time of release.

The end result is an estimate of the maximum rate of introduction of radioactive material which will not exceed the maximum permissible concentration in sea water.

The marine biologist and the oceanographer are essentially concerned with those steps in this general approach dealing with (a) the concentration factors from sea water to the various parts of the marine environment which constitute the return routes to man (i.e., the food chain, beach sand, etc.); (b) rate of transfer of radioactive materials to bottom sediments from solution or suspension in the sea water; (c) advection and turbulent diffusion of the introduced contaminant; (d) the effects of the physical and chemical form of the wastes, and the manner of discharge, on these various processes.

Application of the General Approach to the Estuarine and Coastal Environments

In evaluating the suitability of these two environments as receivers of nuclear wastes, it is particularly essential that adequate basic knowledge be obtained of the various processes involved since, of all marine environments, the

nearshore comes in the most intimate contact with man. The bulk of man's harvest of seafood and other marine products comes from these areas. At the same time, it is these parts of the marine environment which are most likely to receive low level operational wastes from the utilization of nuclear energy.

Other participants at this seminar treat the concentration of activity by marine organisms, and this part of the problem will not be treated further here except for the following observation. Sea water is a complex solution resulting from a geochemical and biochemical balance established over eons of time. Those elements of any radioactive waste material which are likely to remain in solution in the sea for any length of time are for the most part already present in significant quantities as non-radioactive isotopes. Those elements found in very low concentrations in sea water are likely to be precipitated rapidly when introduced into the sea as radioactive wastes. Thus any waste disposal operation is unlikely to change the total amount of any given element in the sea by any appreciable amount, but rather will change the isotopic ratios, or specific activities. Thus if all the strontium 90 which would be produced by the fission of 1,000 tons of uranium 235 (the estimated annual world nuclear power production by the year 2000) at 30 percent efficiency were introduced into a volume of sea water 1 kilometer long, 1 kilometer wide, and 46 meters deep, the total strontium in the volume would be increased by only 1 percent. The resulting activity of over 16 c/ml would of course be extremely high, and no such discharge would ever be contemplated. However, this illustration does emphasize the fact that any waste introduction into the sea would be unlikely to change the amount of strontium already present, to any significant degree.

In the process of biological concentration of certain elements from sea water, there is no distinction between the radioactive isotope of the element and the non-radioactive isotope. The total amount of a given element present in the marine biota is then unlikely to be altered by any waste disposal operation. Also, the total amount of that element resident at a given time in the human body would not be altered by the disposal operation. The essential quantity which should be considered in regard to the safety of man is then not so much the amount of activity per unit volume of sea water, but rather the specific activity. If the evaluation of the per-

missible activity which may be present in sea water without producing an undue risk to man is made using the concept of specific activity, the pertinent factors which must be included are the amounts of the subject element normally present in man and the amount of the element per unit volume of sea water, rather than the concentration factor for the marine biota.

The remainder of this paper treats the processes of advection and dispersion of an introduced pollutant in estuarine and coastal waters, as well as the manner in which the uptake of activity on suspended inorganic material and on bottom deposits might alter the distribution of the pollutant.

MOVEMENT AND DISPERSAL OF AN INTRODUCED POLLUTANT IN ESTUARIES

Consider that a given amount of material, M , contained in an aqueous solution of volume V_0 , is introduced over a short time period into a tidal estuary. The concentration of the effluent prior to entering the waterway is then M/V_0 , and theoretically this is the initial concentration of the pollutant in the immediate vicinity of the point of introduction. Practically, however, this concentration does not occur over any finite time interval or space interval, since the process of introduction of the pollutant into the receiving waters will itself result in some initial mixing between the pollutant and the receiving waters. The initially contaminated volume is then somewhat larger than V_0 , and the initial maximum concentration within the estuary somewhat less than M/V_0 .

The effectiveness of this initial mechanical dilution will depend upon the density difference between the undiluted pollutant volume and the receiving waters, and upon the manner of introduction of the pollutant volume into the estuary. If the density of the pollutant volume differs materially from that of the receiving waters, the initial mechanical dilution as well as later dispersion by turbulent diffusion will be inhibited. If the effluent is introduced into the estuary as a subsurface jet of small cross section, greater initial mechanical dilution will occur than in the case of introduction as a gentle broad flow at the surface or near the bottom. A pollutant volume which is less dense than the receiving waters will spread out on the surface, and one which is more dense will spread out over the bottom. If a pollutant volume less

dense than the receiving waters is introduced near the bottom of the estuary, mechanical dilution will be augmented by the convective rise of the volume through the receiving waters. Likewise, a pollutant volume denser than the receiving waters, when introduced at the surface, will sink through the water column entraining surrounding dilution waters on the way to the bottom.

After initial mechanical dilution the contaminated mixture of pollutant and receiving waters will be transported by the currents in the estuary, and will spread both vertically and horizontally by turbulent diffusion. Tidal currents will carry the contaminated volume back and forth in the estuary over the tidal excursion, and the contaminated volume will participate in the net non-tidal motion. The oscillatory motion of the tide is important in supplying the major portion of the turbulent energy which leads to diffusion. The oscillatory motion of the pollutant with the tidal currents past irregularities in the shoreline, such as embayments and protruding points of land, leads to a longitudinal dispersion of the pollutant in a manner to be described in a later paragraph.

The processes of turbulent diffusion lead to a reduction in the concentration of the contaminated volume with time, and lead to a net transport of pollutant from regions of high concentration towards regions of low concentration. A presentation of the instantaneous spatial distribution of pollutant would reveal a rather irregular picture, with discrete masses of high concentration, surrounded by lows. However, the smoothed horizontal distribution would be approximately bell-shaped, with a central area of relatively high concentrations, and a regular decrease in concentration with distance from the center. With the passage of time the spatial distribution becomes less sharply peaked, and spreads over an ever increasing area.

Vertical diffusion is most intense in layers having vertical homogeneity, that is, where density remains constant over a range in depth. Vertical stability, which results from a rapid increase in density with depth, greatly inhibits vertical diffusion. In many estuaries the surface layers are of lower salinity, and hence less dense, than the deeper layers. In such cases, intermediate depths exhibit a rapid increase in salinity and density which limits the vertical turbulent diffusion. A pollutant intro-

duced near the surface is rapidly mixed vertically within the surface layers, but is only slowly transferred through the region of vertical stability to the deeper layers. Likewise, material introduced into the deeper layers will be rapidly mixed vertically within the layers of weak vertical stability, but will only slowly diffuse into the surface layers through the intermediate depth region of relatively large density gradient.

When a pollutant is introduced as a continuous effluent, as from an outfall pipeline, the contaminated volume spreads down-current in a plume, much like a smoke plume from a smokestack in the atmosphere. The oscillatory motion of the tide in a tidal estuary folds this plume back and forth upon itself, so that the evident features of a plume are masked except very close to the outfall. One convenient way of envisioning the spatial distribution of concentration of the pollutant from a continuous source is to consider the material discharged within each successive infinitesimal time interval as an instantaneous source which will move with the flow, and disperse vertically and horizontally as a result of turbulent diffusion. The spatial concentration distribution at a given time is then the sum of the distributions of all the individual spreading instantaneous sources released prior to the given time.

THE EFFECT OF OSCILLATORY TIDAL MOTION ON THE LONGITUDINAL SPREAD OF POLLUTANT

Tidal oscillations past irregularities in the shoreline are an important mechanism in the longitudinal dispersion of an introduced pollutant. This is made most evident by considering a contaminated volume, produced by an instantaneous release of pollutant, as it is carried up and down the estuary by the tidal currents. Frequently eddies associated with slight embayments or with points of land which project into the estuary will temporarily trap water containing a high concentration of pollutant as the contaminated volume moves past the shore features on one or the other phase of the tide. The main bulk of the contaminated volume is carried on past the shore feature by the tidal current, while the pollutant trapped by the shore feature slowly spreads out into the main stream, leading to an effective dispersal of the pollutant behind the bulk of the contaminated volume.

When the tide reverses, the process is repeated, with a resulting dispersion on the opposite side of the contaminated volume. This mechanism is shown schematically in Figure 2.

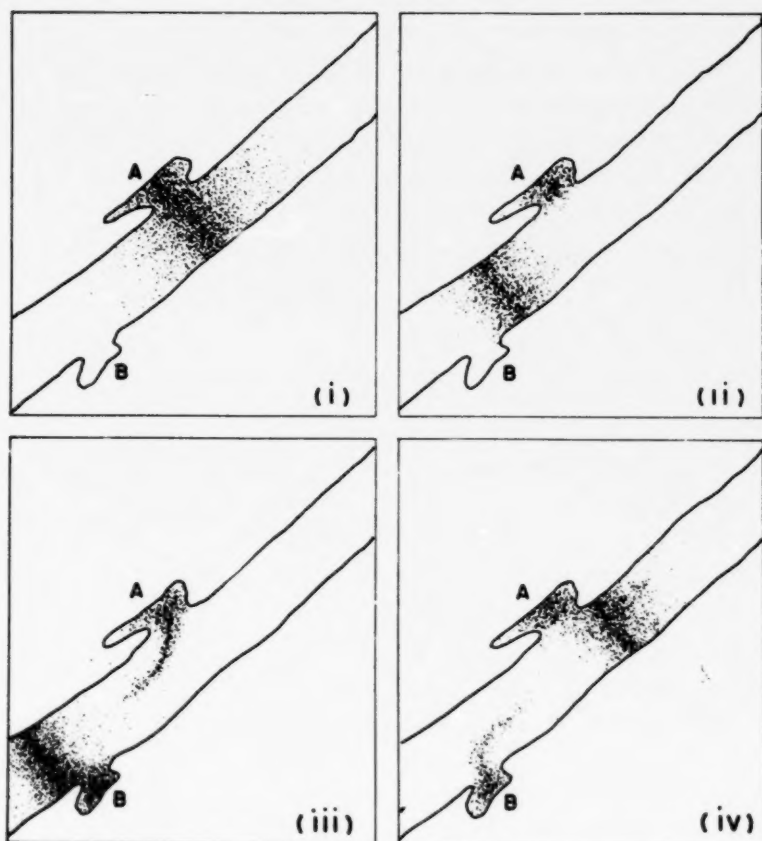


Figure 2. Schematic representation of entrapment by shore features. Concentration is indicated by intensity of shading. As peak concentration of pollution moves downstream on the ebb tide, a portion spreads into shore indenture A, in diagram (i). This portion is entrapped by the indenture as the main volume moves on downstream, as shown in diagram (ii). In diagram (iii) the entrapped pollutant feeds out into the main channel, thus contributing to the longitudinal spread of pollutant, and reducing the concentration. A portion of the main volume is shown spreading into a second shore indenture, B. In diagram (iv) the phenomenon of delayed dispersal following temporary entrapment is repeated for indenture B on the flooding tide.

THE EFFECT OF THE NET NON-TIDAL CIRCULATION ON THE DISPERSION OF AN INTRODUCED POLLUTANT

A discussion of the effect of the net circulation pattern on the dispersal of a pollutant introduced into a tidal estuary requires first

some description of the non-tidal motion in such estuaries. Coastal plain tidal estuaries can be grouped into four classes according to the physical structure of the water and to the net motion.

In a salt wedge estuary the river inflow is large compared to the tidal flow. Sea water enters as a wedge along the bottom, with the fresh water flowing seaward on top of the wedge. If no frictional drag existed between the denser salt water wedge and the lighter river water, the wedge would extend upstream to the point where the river bottom intersected mean sea level. The river inflow would move seaward over the stationary wedge as a thin fresh water layer. In the real fluid we are treating, some frictional drag always exists. The extent of intrusion of the wedge up the estuary depends upon the magnitude of this frictional drag, which in turn depends upon the relative velocities in the upper, seaward flowing layer and in the wedge. Thus the volume rate of flow of the river water which moves seaward on top of the salt water wedge controls the position of the wedge. Under conditions of high river flow the wedge extends only a short distance into the estuary, while for low river flows the wedge extends many miles upstream. The Mississippi River is an example of this salt wedge estuary. When the flow in the Mississippi is low the undiluted salt wedge extends upstream for over one hundred miles. Under conditions of high river flow the salt wedge extends only a mile or so above the mouth of the river.

Comparatively little mixing occurs at the interface between the seaward flowing upper layer and the salt wedge; hence the salinity throughout the wedge is nearly that of full sea water. At the upper boundary of the wedge unstable interfacial waves form and break into the upper layers, producing a slowly increasing salt content in these layers as they move seaward. Even so, a very sharp vertical salinity gradient exists between the upper layer of relatively low salinity and the salt wedge. For a given river flow the horizontal position of the wedge and its vertical dimension remain stationary. The loss of salt water from the wedge to the upper layer must be compensated for by flow of water into the wedge from the sea. Since this loss of salt water to the upper layer takes place all along the upper boundary of the wedge, there must be, in order to maintain the position and shape of the wedge, a flow directed towards the upstream tip of the wedge at all positions

within the wedge. Thus the circulation pattern in this salt wedge estuary involves a seaward flowing upper layer riding over the landward directed flow in the salt wedge. The compensating flow in the wedge is small compared to the seaward flow of the low salinity surface layers.

If a pollutant with an initial density equal to or greater than the receiving waters is introduced into the deep layers of a salt wedge estuary, the contaminated volume disperses only very slowly within the wedge, since the currents there are weak. The waste is carried by the slow upstream directed flow to the very tip of the wedge. The process of upward exchange of water from the wedge slowly transfers contaminated water to the seaward flowing upper layer. Once in the upper layer, the waste is carried seaward with the surface water layers and transported out of the estuary. The time required to flush the wastes from the estuary in this case is relatively long, since the rate of transfer of the waste from the salt wedge to the surface layers is slow.

A pollutant introduced into the surface layers of a salt wedge estuary, with an initial density equal to or less than the receiving waters, is rapidly flushed from the estuary with the seaward flowing surface waters. None of the contaminated water enters the salt wedge, since exchange across the upper interface of the wedge is essentially one way, directed from the wedge to the fresher surface layers.

In a partially mixed estuary, tidal movements are large compared to the river inflow, vertical mixing is sufficiently strong to destroy the sharp boundaries separating the salt wedge from the upper layer, and the wedge ceases to exist as a readily identifiable feature. There still exists a transition layer of relatively rapid increase in salinity with depth, called the halocline, which separates the lower salinity surface layers from the higher salinity deeper water. The salinity in both the surface layers and the bottom layers decreases steadily from the mouth to the head of the estuary. Most of the estuaries along the eastern coast of the United States fall into this class of partially mixed estuaries.

The oscillatory tidal currents produce the most obvious motion in these partially mixed estuaries. Superimposed on the tidal currents

there is a net circulation pattern, with a net seaward flow in the surface layers, and a net flow directed from the mouth towards the head of the estuary in the deeper layers. There is also a small net vertical motion directed from the deeper layers to the surface layers. The volume of water flowing toward the head of the estuary per unit time decreases as one proceeds from the mouth to the head of the estuary since water is being transferred through vertical motion from these deeper layers to the surface layers. Hence, the volume rate of seaward flow in the surface layers increases as one proceeds from the head towards the mouth of the estuary.

The flows involved in this net circulation pattern in partially mixed estuaries are many times larger than the fresh water inflow. This results from the potential energy gained through the tidal mixing. The center of gravity of a column of water with the upper half fresh and the lower half salt water will be raised when the two halves are mixed together. Thus kinetic energy of the oscillatory tidal motion is transferred through the disorganized motion of turbulence to increased potential energy of the water column, which in turn provides for increased kinetic energy of the net circulation pattern.

A pollutant initially introduced into the bottom layers in a partially mixed coastal plain estuary, in addition to participating in the oscillatory movement of the tidal currents, is carried in the net motion toward the head of the estuary. At the same time, turbulent mixing leads to horizontal dispersion in both the longitudinal and lateral directions, and to vertical dispersion into the surface layers. The pollutant which becomes mixed with the surface layers is carried in the net flow toward the mouth. Seaward from the point of introduction, the pollutant being carried toward the ocean in the surface layers is partially mixed downward into the deeper layers, and reintroduced into layers moving toward the head of the estuary.

A pollutant introduced into the surface layers is initially carried in the net flow toward the mouth of the estuary. Turbulent mixing leads to both horizontal and vertical dispersion, and the wastes are thus also added to the deeper layers having a net flow directed towards the head of the estuary.

In the region of the estuary headward from the point of introduction, the concentrations of

the pollutant will always be greater in the deeper layers than in the surface layers while seaward from the point of introduction the converse will be true. These conditions prevail regardless of whether the wastes are initially introduced into the surface layers or into the deeper layers.

The pollutant is ultimately flushed from the estuary in the seaward directed flow of the surface layers.

Vertically homogeneous estuaries form a third group of waterways, in which tidal movements are very large compared to the motion induced by the inflowing fresh water. The mixing induced by the tidal motion completely overcomes the stability resulting from the fresh water inflow, producing uniform salinity from surface to bottom. The salinity decreases from the mouth to the head of the estuary. Also, in relatively wide estuaries in the northern hemisphere, the salinity on the right side (looking toward the mouth) will be lower than the salinity on the left side, as a result of the effects of the earth's rotation. For the southern hemisphere the converse is true.

The circulation pattern in a vertically homogeneous estuary shows no variation in water movement with depth. In relatively wide estuaries, net seaward flow occurs along the right side (looking toward the mouth of the estuary), and a net motion directed toward the head of the estuary occurs on the left side. A laterally directed flow carries water from the left side of the estuary to the right, and large scale horizontal mixing occurs between the counter-flows on the two sides of the estuary.

A pollutant exhibiting no marked density difference with the receiving waters will rapidly show a uniform depth distribution when introduced into a vertically homogeneous estuary. If the point of introduction is on the right hand side of the estuary (looking seaward) the contaminated volume will be carried toward the mouth with the net flow. At the same time lateral turbulent diffusion will lead to a transport of some of the pollutant into the waters on the left side of the estuary. Here the pollutant will be carried towards the head of the waterway in the net flow pattern.

If the point of introduction is on the left side of the estuary, the contaminated volume is initially carried towards the head of the estuary

in the net flow pattern. The transverse flow plus lateral diffusion provides for a transport of pollutant to the right side of the estuary, where the predominant flow is seaward.

The pollutant is ultimately flushed from the estuary in the predominant seaward flow on the right side of the estuary.

Sectionally homogeneous estuaries are comparatively narrow, vertically homogeneous waterways where tidal mixing is sufficient to destroy the lateral salinity gradient. The only variation in salinity is the decrease from the mouth to the head of the estuary. The net circulation pattern is quite simple, being a slow seaward movement at all depths.

In such estuaries an introduced pollutant is rapidly mixed vertically and horizontally. The contaminated volume is carried back and forth with the oscillatory motion of the tidal currents, is dispersed up and down the estuary by turbulent diffusion, and is slowly carried seaward with the net flow.

THE THEORY OF DISPERSION OF A WATER-BORNE POLLUTANT

The local time rate of change of concentration of a conservative, waterborne pollutant is controlled by the processes of advection and diffusion. Motion in an estuary is always turbulent in character, and it is not possible to describe adequately the instantaneous field of motion. The velocities which enter the advective term are actually temporal and spatial means. The time period and the distance over which the average is taken depend upon the measuring equipment as well as the spacing of observations. The process of diffusion involved is turbulent mixing rather than molecular diffusion.

Consider a rectangular coordinate system with the x_1 axis directed longitudinally down the estuary, the x_2 axis directed laterally across the estuary, and the x_3 axis vertically downward. The differential equation expressing the local time rate of change of concentration of a pollutant is given by:

$$(1) \quad \frac{\partial \zeta}{\partial t} = -v_1 \frac{\partial \zeta}{\partial x_1} - v_2 \frac{\partial \zeta}{\partial x_2} - v_3 \frac{\partial \zeta}{\partial x_3} + \frac{\partial}{\partial x_1} \left[K_1 \frac{\partial \zeta}{\partial x_1} \right] + \frac{\partial}{\partial x_2} \left[K_2 \frac{\partial \zeta}{\partial x_2} \right] + \frac{\partial}{\partial x_3} \left[K_3 \frac{\partial \zeta}{\partial x_3} \right]$$

where C is the concentration at the point (x_1, x_2, x_3) at the time t ; v_1, v_2, v_3 are the x_1, x_2 and x_3 components of the velocity; and K_1, K_2, K_3 are the coefficients of eddy diffusion.

This equation is too complex for analytical solution. In this three dimensional form no existing high speed computing machine has adequate memory for numerical solution of a specific case. In addition, no adequate general theory exists for the determination of the diffusivity coefficients. These difficulties have led to attempts to justify the reduction of the equation to two or, in many cases, one spatial dimension.

Even in the case of the one-dimensional and two-dimensional forms of the diffusion equation it is necessary to make simplifying assumptions regarding the velocity field and the diffusivities in order to obtain analytical solutions. Numerical solutions for the one-dimensional case have been made successfully, and attempts to solve specific diffusion problems by numerical solution of the two-dimensional form of the equation are now in progress. In these numerical approaches, the observed distribution of salinity is employed in determining the appropriate diffusion coefficients. It is necessary to assume some initial distribution of the pollutant, and to include the conditions imposed by the physical boundaries of the estuary.

Pritchard (1954) showed that in certain partially mixed estuaries the distribution of salinity is related primarily to the horizontal advective term, the vertical advective term, and the vertical diffusion. These same processes would then control the distribution of an introduced pollutant in such estuaries. Using these results Kent and Pritchard (1957) showed that the vertical diffusivity in a partially mixed estuary was compatible with the generalized mixing length concept, provided the effects of vertical stability and wind induced turbulence were included. These studies offer the possibility that the vertical diffusivity may be determined for a given estuary from measurements of the field of motion, the vertical density distribution, and the bathymetry of the estuary.

Stommel (1953) presented a technique for obtaining the steady state distribution of a pollutant introduced as a continuous source in a sectionally homogeneous estuary. The procedure involves the numerical solution of the one-

dimensional form of equation (1), under steady state conditions, using the method of relaxation.

Kent (1958) developed a difference equation for the one-dimension form of equation (1) suitable for numerical integration using the IBM 650 high speed computing machine. He compared the computed distribution of concentration as a function of time and position resulting from an instantaneous release of tracer dye with the distribution observed in the Delaware estuary model at Vicksburg, Mississippi. The salinity distribution was employed by Kent in computing the longitudinal diffusivity. By applying a correction factor to the diffusivities thus determined, which depended on the ratio between the size of the polluted volume and the length of the estuary, Kent was able to closely match the observed distribution of pollutant with his numerical integration. Figure 3 shows the comparison of the observed and computed distributions for one of the tests.

SPECIAL SOLUTIONS TO THE DIFFUSION EQUATION

Under conditions of constant velocity and constant diffusivity, analytical solutions to equation (1) can be obtained. However, the vertical diffusivity is a function of the vertical stability of the water. Vertical mixing is large in layers which show little variation of density with depth, but is greatly inhibited in layers which show a large rate increase of density with depth. In regions far removed from any physical boundary the longitudinal and lateral diffusivities are probably equal to each other, but these horizontal diffusion coefficients appear to be directly related to the size of the diffusing volume. Physical boundaries in estuaries and coastal waters will lead to further spatial variations in the diffusivities. Hence the application of these special solutions for constant eddy diffusivities to estuarine and coastal environments is of questionable value.

Recently Joseph and Sender (1958) developed a special solution applicable to the two-dimensional diffusion of an instantaneous vertical line source. In this solution the variation of diffusivity with distance from the center of the diffusing volume was included. These authors showed that their solution was applicable to a larger size range of diffusion phenomena in the ocean.

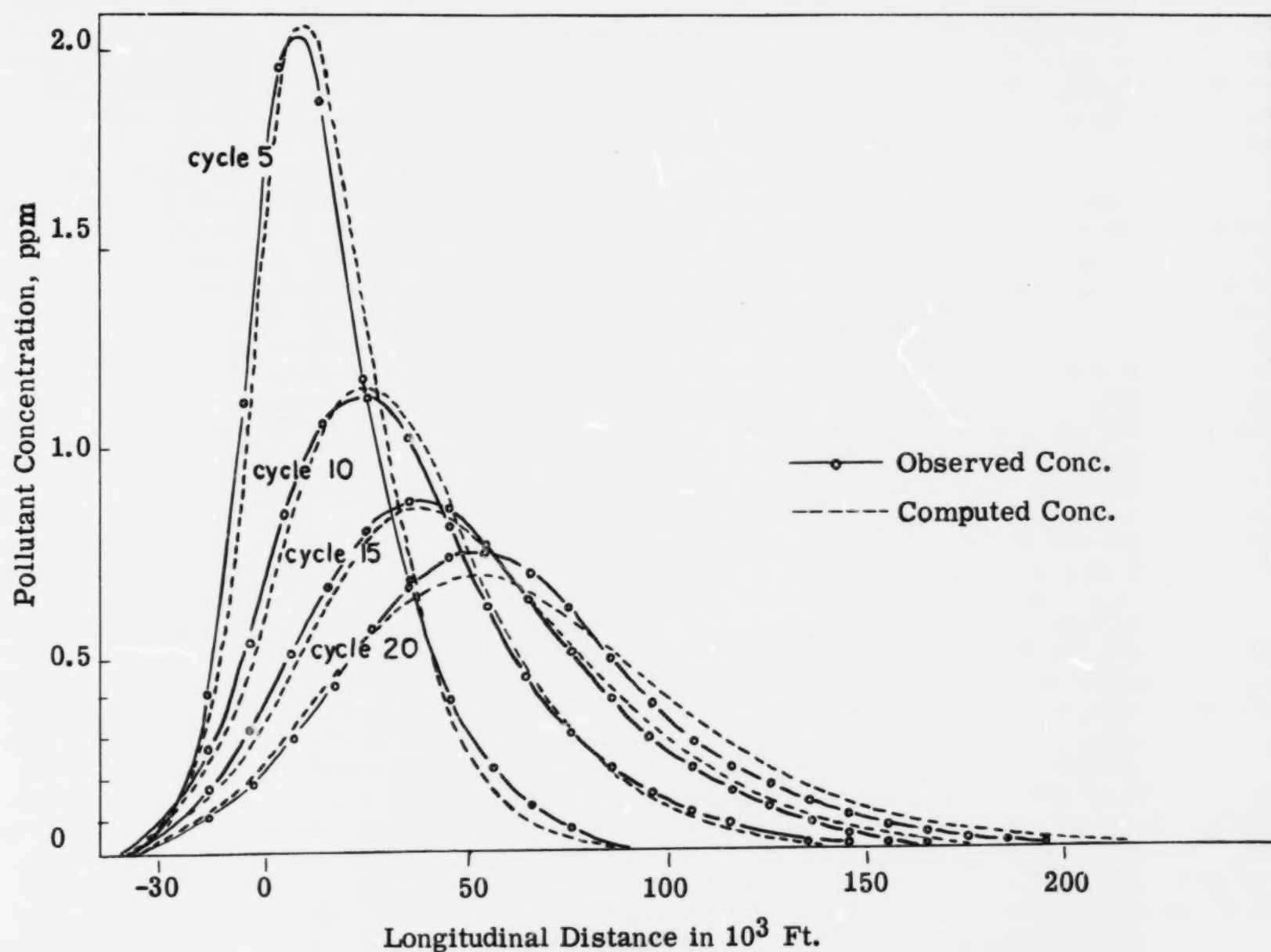


Figure 3. Observed and computed pollutant concentration as a function of longitudinal distance from release point in Delaware estuary model (after Kent, 1958).

The solution of Joseph and Sender applies to a water body of infinite horizontal extent. An approximate approach to the utilization of their development is to assume that the physical boundaries of estuaries and coastal waters simply restrict the size of the arc within which dispersion can proceed. Under these conditions the applicable equation can be obtained from the Joseph and Sender solution by the method of reflection. These authors' same basic approach can also be applied to the problem of one spatial dimension, thus obtaining a solution applicable to a sectionally homogeneous estuary.

These solutions apply to the case of diffusion from an instantaneous release of pollutant. Equations applicable to a continuous discharge

of pollutant can be obtained from the equations of Joseph and Sender by using certain simplifying restrictions.

These special solutions of the diffusion equation have not yet been adequately tested for applicability to estuaries and coastal waters. Preliminary investigation indicates that considerable modification will be required to account for the complex boundary conditions as well as the variability in mixing intensity which are found in these environments.

THE USE OF HYDRAULIC MODELS

One very promising empirical approach to the evaluation of the movement and dispersion

of a pollutant introduced into a given estuary is through the use of properly scaled hydraulic models of the waterway in question. Mr. Henry Simmons treats this application of models in another paper scheduled for discussion at this seminar.

While it appears likely that the large scale features of movement and dispersion are reproduced in the model, some question exists regarding the reality of the diffusion phenomena in the model in the close vicinity of the discharge point and during the early stages of mixing. In any case, hydraulic models offer the best immediate possibility of dealing with the three-dimensional case and of treating the complex boundary conditions. The large costs of models capable of adequately reproducing the prototype conditions suggest the desirability of continued work on analytical and numerical approaches to the problem.

UPTAKE OF RADIOACTIVE MATERIAL ON SUSPENDED MATTER AND ON BOTTOM SEDIMENTS

The discussion of movement and dispersion of a waterborne pollutant given above cannot be applied directly to all components of the potential radioactive waste material, since some isotopes will occur in particulate form in sea water, and others will be rapidly taken up on the

suspended silt and on bottom sediments by processes of adsorption and absorption. Since estuaries and coastal waters are normally quite turbid, these phenomena will be quite important in such environments.

Settling of the particulate material and uptake by bottom sediments will result in removal of activity from the water, and concentration of this activity in the bottom materials. In some cases this can be advantageous, since radioactive material tightly bound to the bottom sediments would not readily enter the food chain and return to man. In other situations bottom living filter feeders and detritus feeders might further concentrate activity directly from the bottom materials, in which case deposition of radioactive wastes onto the bottom would be detrimental.

Carritt and Harley (1957) discuss the available information on uptake by suspended solids and precipitation of fission products in sea water. The data are not conclusive and this area requires a great deal of further study. The experience of the British at the Windscale Atomic Energy Works, where approximately 100,000 curies per year are being introduced by pipeline into the coastal waters of the Irish Sea, indicates the significance of precipitation and uptake by suspended matter and bottom sediments. Here apparently a large part of the wastes is removed from contact with the food chain by these processes.

REFERENCES

- Carritt, D. E., and J. H. Harley. 1957. Precipitation of fission product elements on the ocean bottom by physical, chemical, and biological processes. *The Effects of Atomic Radiation on Oceanography and Fisheries*, Pub. 551, Nat. Acad. Sci. - Nat. Res. Council, 60-68.
- Joseph, J., and H. Sender. 1958. Horizontal diffusion in the sea. *Deut. Hydrog. Zeit.*, 11 (2), 49-77.
- Kent, R. E., and D. W. Pritchard. 1958. A test of mixing length theories in a coastal plain estuary. *J. Mar. Res.* (in press).
- Kent, R. E. 1958. Turbulent diffusion in a sectionally homogeneous estuary. Tech. Report XVI of Chesapeake Bay Institute, April 1958.
- Pritchard, D. W. 1954. A study of the salt balance in a coastal plain estuary. *J. Mar. Res.*, 13 (1), 133-144.
- Stommel, Henry. 1953. Computation of pollution in a vertically mixed estuary. *Sewage and Indust. Wastes*, 25 (9), 1065-1071.

POLLUTION PROBLEMS CREATED BY POWER REACTORS AND OTHER USES OF ATOMIC ENERGY

Conrad P. Straub - Chief, Radiological Health Research Activities, Division of Radiological Health, Robert A. Taft Sanitary Engineering Center

ABSTRACT

Many sources contribute to the radioactivity levels in the hydrosphere. These sources include natural radioactivity from the geosphere and atmosphere, naturally occurring radionuclides from uranium and thorium mining and milling operations, and from nuclear energy applications - reactor operations, fuel reprocessing, beneficial applications, and fallout.

The nature and quantities of radioactive materials released from each of the above named sources is defined and the effects on the hydrosphere delineated. Some indication is made of the fate of those materials in the environment pointing out that consideration must be given to the concepts

To gain some concept of the magnitude of the potential pollution problem arising from the use of nuclear energy, the specific sources of potential radioactivity pollution by states have been indicated under several categories in Figures 1 through 4. These categories include: (Figure 1), reactors -- civilian power, research and training, mobile (propulsion), and miscellaneous (test, experimental, land based military, etc.); (Figure 2), Atomic Energy Commission facilities -- laboratories and feed material plants; (Figure 3), fuels -- uranium processing plants, enriched fuel materials, and enriched fuel fabrication; and (Figure 4), miscellaneous -- waste disposal services, isotope users, and scrap recovery operations.

The numbers of sources involved in each of the above classifications are: Reactors, 104; AEC facilities, 23; fuels, 44; and miscellaneous, 4439, for a total of 4,610 sources. These numbers include all past and current operations with a start-up date in 1959. These data are as of approximately December, 1958.

From these Figures it will be seen that no state is immune from potential radioactive contamination.

In addition to the above sources, others include the naturally occurring radionuclides,

of temporary storage, improved subsequent treatability, and return of radioactive materials to the food chain and biological cycle of man.

In the environmental release of radioactivity, consideration must be given to the total exposure or total intake. This involves the recognition of radioactivity contributed from all sources -- industrial exposure, water intake, inhalation, food supply, etc. The downstream uses of the hydrosphere and the base line exposure of the downstream population may be of more importance in arriving at the permissible levels of discharge than the maximum permissible values recommended for drinking water alone.

such as uranium, radium, potassium-40, and others, and the various radionuclides contributed from fallout, which cover a wide range of fission products as well as several species of induced isotopes. Figure 5 represents a summary of fallout levels encountered in various environmental media at Cincinnati, Ohio. It will be seen that the gross measured radioactivity levels in rainfall are approximately one million times greater than gross radioactivity levels in air. The reduction in rainfall activity levels in terms of cistern water supplies and surface water supplies also is indicated. These sources must be considered in the evaluation of any contamination problem, since they provide, for lack of a better word, a so-called "background". This "background" must be subtracted to determine the actual contribution of specific radioactive materials from any given source of radioactivity. However, this does not mean that the contribution of radioactivity from either natural sources or from fallout should be neglected in determining the total effect of radiation on man and his environment.

STREAM EFFECTS

Let us now divert our attention to the effects of such releases of radioactivity on the hydrosphere -- essentially in a stream environment.

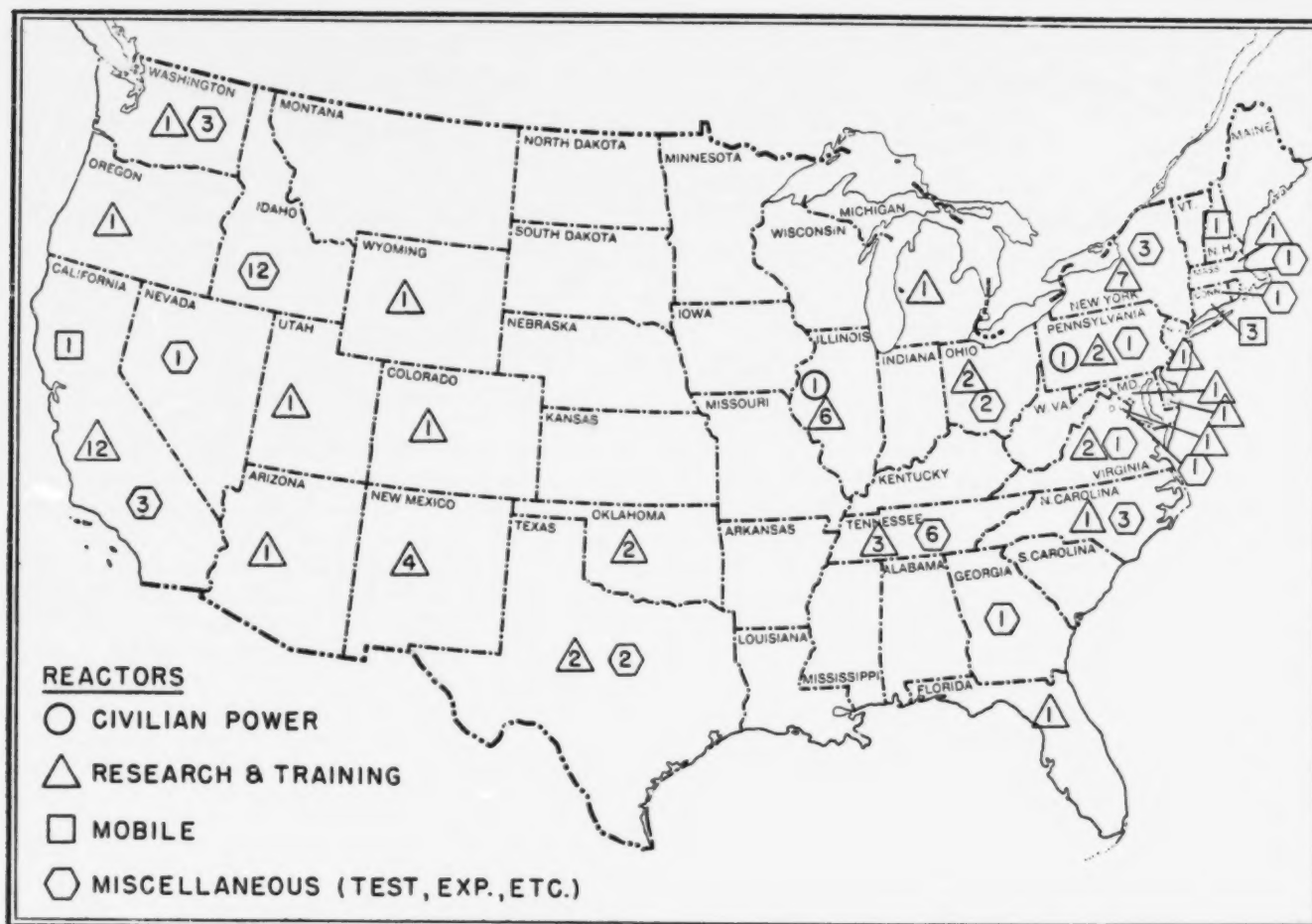


Figure 1

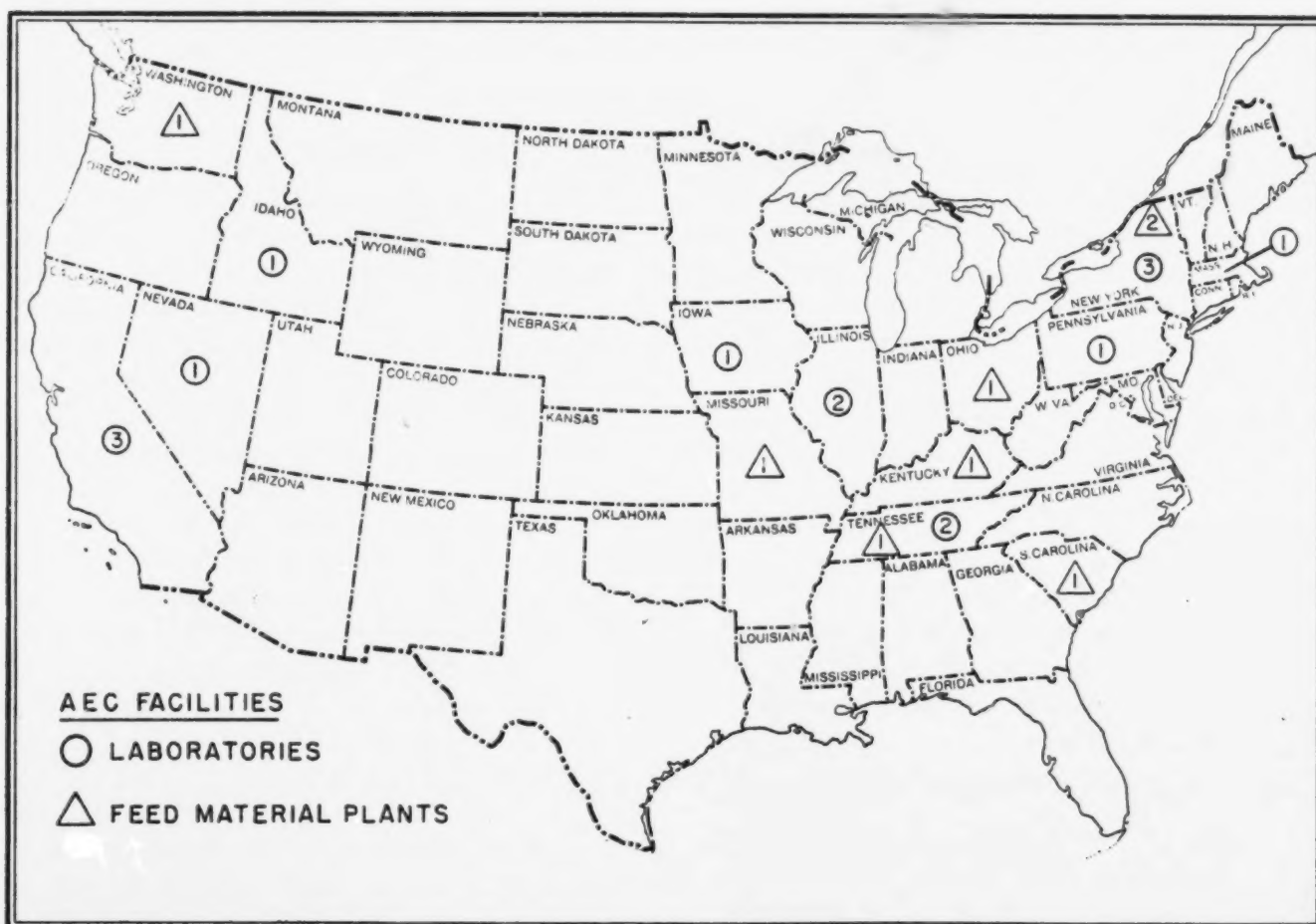


Figure 2

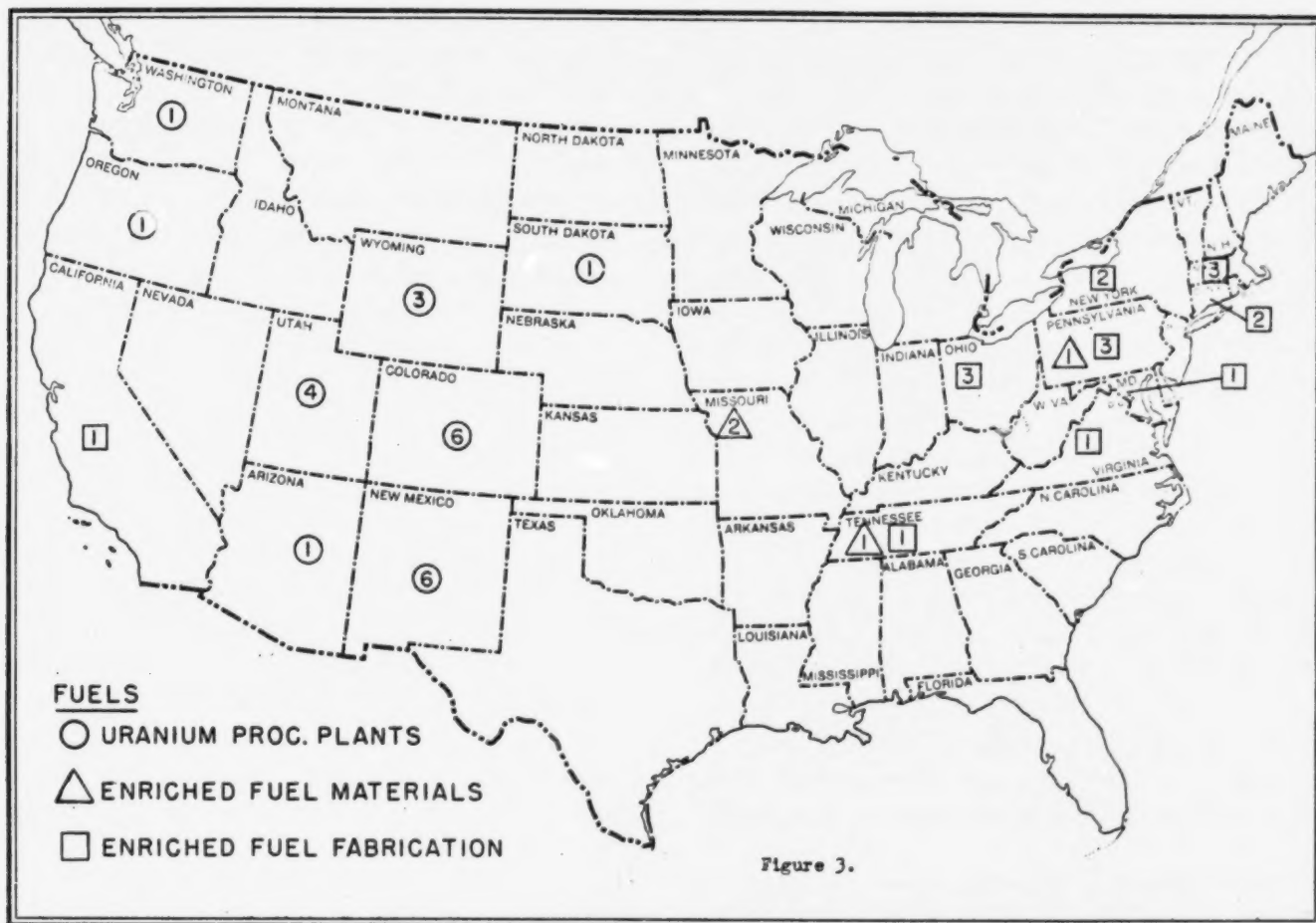


Figure 3

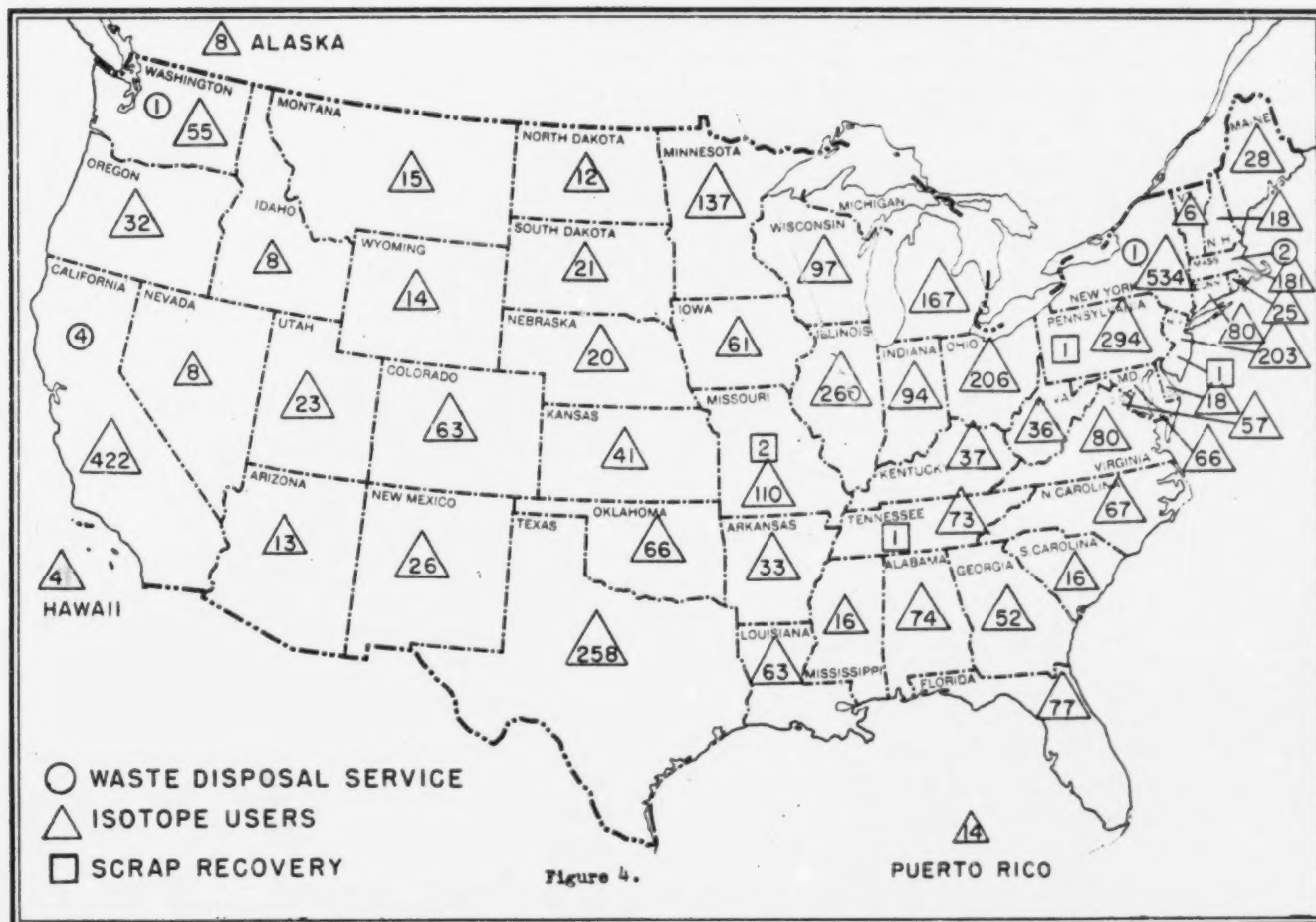


Figure 4

What forces are active in the temporary removal of the specific radionuclides discharged into the stream environment, and what forces are operative in returning this material to add to the radiation exposure of man? In other words, what probability is there that the radioactivity discharged will result in the direct exposure of man?

What can happen to any radionuclide discharged into the stream environment? The forces active in the temporary removal of activity may be tentatively categorized as being of a chemical, physical, or biological nature.

Chemical combination, i. e., reaction between the radionuclide in the waste stream and the water environment, will cause some of the particles to precipitate out, others to be adsorbed on surfaces (turbidity or other particles in the liquid phase), or on the bottom muds. In other cases, ion exchange may take place with the exchange of radionuclides with other isotopes.

Physical forces will also act upon the radionuclides discharged. These include temperature, velocity and flow, diffusivity, bottom characteristics, the effect of impoundments, etc. In addition, radionuclide decay will have a significant bearing upon the problem. Obviously, short-lived radionuclides may decay out before the water reaches the first point of downstream use. Dilution also must be considered but it must be remembered that dilution does not remove activity from the environment. Only the concentration has been reduced but the total amount of activity is constant. A knowledge of stream movement is absolutely essential because it helps to define the time required for specific radionuclides to reach various points downstream.

Biological factors will certainly exert influences upon the radionuclides in the stream environment. These include assimilation, where the specific radionuclides may be metabolized by the normal flora and fauna and utilized in the formation of tissue material. Uptake itself on a per gram basis of organism may be misleading and consideration should be given to reporting activity levels as a function of the volume of water from which the mass of organisms was collected. In other words, uptake should be related to productivity. Adsorption will also have to be considered. Here the material is adsorbed on surfaces and retained there for

some period of time. In the same way there may be exchange between specific materials that are adsorbed on the surface of the biological material or which may be directly exchanged with the specific plant. This point may be particularly applicable where stable materials of higher concentration may be discharged subsequently and will exchange or dilute with the radioactive material that may have been deposited there earlier.

FACTORS RESPONSIBLE FOR RETURN OF TEMPORARILY REMOVED RADIOACTIVITY

Let us now focus our attention on some of the factors responsible for releasing the radioactivity temporarily removed by the mechanisms previously described and making it available again for the potential exposure of man. A change in the chemical properties of the waste materials discharged or the stream itself may solubilize some of the previously deposited material or may minimize the combination of the specific chemical agents in the two media, thus causing it to move further downstream. Obvi-

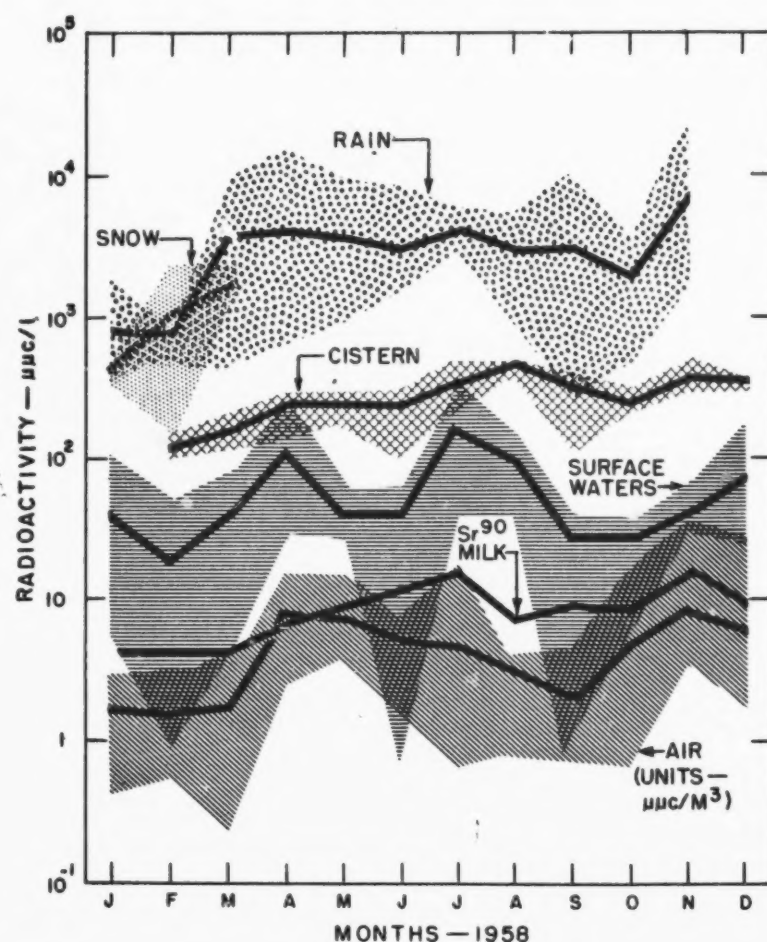


Figure 5. Radioactivity levels-Environmental samples - Cincinnati, Ohio, 1958.

ously, the chemical form of the material is of considerable importance. Where exchange is a mechanism, the chemical form of the material is important. Anionic or non-ionic substances, for example, will not be removed by the turbidity or the bottom muds but will be moved downstream. The release of increased quantities of stable materials will reduce the uptake of the radionuclide. Where material is already adsorbed, the addition of such diluting stable materials may be responsible for the return of radioactivity previously removed. Upstream saturation of surfaces, whether through ion exchange, adsorption or other mechanism, will tend to cause the movement of subsequent contaminants downstream. From this it is obvious that, given sufficient time, the longer-lived radionuclides will continue to move downstream.

Radioactivity removed previously by physical mechanisms may be returned to the environment by any of the following methods. Previously settled or deposited activity may be picked up during times of flood and moved downstream. The same applies to previously adsorbed or exchanged materials. Non-uniformity of flow across the stream channel, due to short circuiting, temperature gradients, density gradients, etc., may account for the movement of much higher levels of activity than those predicated on a straight out-and-out dilution calculation.

Biological factors are also responsible for increased levels of concentration under certain sets of circumstances. We all know that certain biological forms will concentrate specific radionuclides to many times the levels found in the water environment. Upon the decay or destruction of these organisms, much greater amounts of radioactivity may be released into smaller volumes of water resulting in considerably higher concentrations of activity during these times. It is also possible that when the levels of activity in the water environment drop, the activity from the biological forms may be released slowly back to the water environment. Finally, there is the possibility of return of radioactivity to the water environment as a part of the excretion process of the organisms.

From the above, it will be seen that there are a large number of factors influencing the temporary retention and return of radioactivity from one phase of the environment to another. In addition to an evaluation of these factors, one

must take into consideration the downstream uses of the water itself. For example, soluble radioactivity contained in waters used for irrigation may be exchanged with soil on contact and subsequently returned to man by plants picking up the activity through their root systems. The effects of radioactivity levels upon the use of the water environment for recreational purposes or for industrial uses must be clearly evaluated. This means that a continuous examination of the effects of any discharges of radioactivity upon the downstream environment is necessary if one is to prevent or minimize potential damage either to man or his environment.

An additional advantage, gleaned from the temporary storage or holdup of radioactivity, is the effect on the subsequent treatability of the radionuclides present. Soluble radioactivity adsorbed or exchanged on particulate matter or assimilated by biological material, may be removed by water treatment, particularly where coagulation and filtration are included. For example, strontium-90 or cesium-137, which, when in solution, is removed to a minor extent by coagulation and filtration, may be removed completely when associated with particulate matter.

MPC VALUES VS. TOTAL UPTAKE CONCEPT

Blind adherence to currently published permissible concentration values is unreasonable because these do not take into consideration changes that may take place in the release of this material as it moves through the environment. It is necessary to know what specific radionuclides are discharged into the environment, and in what concentrations, and in what form they may be returned, and their relation to all other potential sources of exposure. As a simple approach to this way of thinking, some data are presented on the potential intake of strontium-90 in Cincinnati on a day-by-day basis through the air, water (cistern or surface supplies), milk, and food sources (see Table 1). It will be seen that air contributes the least amount of strontium-90 on a day-by-day basis, contributing only 0.002 to 0.24 $\mu\mu\text{C}/\text{day}$. Water, on the other hand, depending upon concentration, may add quite a bit to the daily intake of this radionuclide. In the case of cistern water supplies we find that the intake may vary from approximately 0.7 to 16.5 $\mu\mu\text{C}/\text{day}$. In the case of surface water supplies these values are a little

Table 1. Radioactive contamination - Environmental sources
Cincinnati data

Source	Radionuclide activity level - $\mu\mu\text{c}/\text{l}$, $\mu\mu\text{c}/\text{M}^3$, $\mu\mu\text{c}/\text{kg}$	Daily intake ml or grams	Intake of radionuclide $\mu\mu\text{c}/\text{day}$	Source of data
Air	Sr^{90} - 10^{-4} - $1.2 \times 10^{-2} \mu\mu\text{c}/\text{M}^3$	2×10^7 ml	0.002 - 0.24	AEC, 1958
Water - Cistern or	Sr^{90} - 0.3-7.5 $\mu\mu\text{c}/\text{l}$	2,200 ml	0.7 - 16.5	
Surface	Sr^{90} - 1-5 $\mu\mu\text{c}/\text{l}$	2,200 ml	2.2 - 11	
Milk	Sr^{90} - 8.5 $\mu\mu\text{c}/\text{l}$	1,000 ml	8.5	Campbell, 1959 Murthy
Food	Sr^{90} - 0.2-60 $\mu\mu\text{c}/\text{kg}$	1,200 gm	7	
Totals			(16.2-17.7) min. (26.2-32.2) max.	
Percent of permissible intake (based on water)			(9-10)-(15-19) percent	

lower, ranging essentially from 2.2 to 11 $\mu\mu\text{c}/\text{day}$. In Cincinnati, the strontium-90 content of milk during 1958 averaged 8.5 $\mu\mu\text{c}/\text{l}$ and, assuming an intake of one liter of milk per day, represents a daily intake of 8.5 $\mu\mu\text{c}/\text{day}$ of strontium-90. Assuming a normal diet pattern, the concentration for strontium-90 in food materials varied from 0.2 to 60 $\mu\mu\text{c}/\text{kg}$ and, with an intake of approximately 1200 gm, this would account for a daily intake of 7 $\mu\mu\text{c}/\text{day}$. These figures show that the minimum daily intake ranges from 16.2 to 17.7 $\mu\mu\text{c}/\text{day}$, depending upon whether one has as a source of water supply either cisterns or surface supplies, or 26.2 to 32.2 $\mu\mu\text{c}/\text{day}$ as a maximum value.

If we compare the daily intake of strontium-90 to the permissible lifetime (i.e., 70 yrs.) intake for water ($80 \mu\mu\text{c}/\text{l} \times 2.2 \text{ l/day} = 176 \mu\mu\text{c}/\text{day}$), it will be seen that the intake represents 9 to 19 percent of the allowable daily intake of this particular radionuclide, insofar as "standard adult man" is concerned. This, of course, does not represent the total exposure and similar calculations must be carried out based on the intake of other radionuclides. Consideration should be given also to the body burden levels in different age groups. In addition, one must not fail to recognize that in certain circumstances individual levels in various media

may be considerably higher than these indicated here. It must also be recognized that under certain circumstances water, milk and food may contribute similar amounts of radioactivity; in other cases, where the levels of strontium-90 in water may be low, as in the case of ground water supplies, the bulk of the activity is contributed through milk and food materials. (Another factor to remember is that MPC's are for lifetime exposures. Insofar as man changes his living habits and patterns -- these changes should also be considered).

CONCLUSIONS

The approach indicated herein is felt to be far more logical than that of a direct comparison of the concentration levels in either water, milk, or food to the maximum permissible concentration levels currently recommended for air and water. The intake concept appears to be much more reasonable since it takes into account the actual intake of these specific materials regardless of their source.

As a final remark, consideration must also be given to the discharge of stable materials into the stream environment, some of which may be toxic at the levels discharged. Before release to the stream environment their effects should be investigated and evaluated.

REFERENCES

U. S. Atomic Energy Commission. Environmental Contamination from Weapons Tests. Report HASL-42, pp. 39-40. Health and Safety Laboratory, New York Operations Office, New York (October, 1958).

Campbell, J. E., G. K. Murthy, A. S. Goldin, H. B. Robinson, C. P. Straub, F. J. Weber, and K. H. Lewis. The Oc-

currence of Strontium-90, Iodine-131 and Other Radionuclides in Milk, May 1957 through April, 1958. Am. Journal Public Health, Journal Public Health, 49(2):225-235 (1959).

Murthy, G. K. Unpublished information.

PANEL SUMMARY

Lauren R. Donaldson, Chairman

Radioactive wastes recently have joined the parade of the evergrowing number of pollutants in our aquatic environment. The cooling waters from atomic piles, waste from laboratories, even the air-borne fallout materials from nuclear weapons tests deposited on terrestrial areas, follow the natural "downhill flow," with water runoff to rivers, lakes and eventually to the seas.

Radioactive pollution differs from most pollutants in two very specific ways. (1) Radioactive wastes, unlike some other pollutants, can be measured accurately as to amount and kind. The detection of radioactive wastes in minute amounts -- in parts per million, billion, or trillion and almost to the specific atom can be made by radiological methods. Radiological techniques make possible, as well, the identification of the exact isotopic form of the element. (2) Very exacting standards of tolerance which are international in application and acceptance already have been established for biologically important radioisotopes, whereas tolerance limits have not been established for some of the pollutants that have been with us for a much longer time.

I do not mean to imply by the foregoing remarks that there are no problems in the detection and evaluation of radioactive wastes in our waters. Quite to the contrary, there are many problems to be solved, and only by very hard, patient work can we as biologists, using our best talents and the "tools" provided by other disciplines -- engineering, chemistry and physics -- hope to make reasonable progress in understanding the role of radioactive wastes in our aquatic environment.

During the earlier discussions, the panel presented some of the problems, explained methods used in the attack on the problems presented, and summarized some of the results of their efforts.

One of the major areas of interest in the field of radioactive waste in an aquatic environment is in the Western Pacific at and near the Eniwetok

Test Site in the Marshall Islands. Since 1946, there have been repeated nuclear tests in which a great variety of kinds and sizes of weapons have been tested. Biological evaluations have been a part of every test program -- not always high on the preferred list of investigations, but on the list.

As a result of the evaluations in the Western Pacific sponsored by the Division of Biology and Medicine of the U.S. Atomic Energy Commission, a great deal has been learned about the fate of radioactive materials -- both fission and non-fission -- that fall into the sea, on the islands, in the lagoons and over the shallow areas of the reefs. The twelve years of study by hundreds of specialists from many disciplines have taught those of us who have been part of the program a very healthy respect for the "power of the atom." There also has come an understanding of the behavior of radioactive waste in a natural environment and the steps essential to living with it.

A few days after fallout from a weapons test, a large portion of the radioactive materials produced is absorbed or adsorbed by the organisms in the sea, principally by the plankton; therefore, the distribution of the radioisotopes in the sea is determined to a great extent by the biota. As the vertical, diurnal movements of the plankton are often from the fast-moving surface currents to the slow-moving currents below the thermocline, the rate of advance of the plankton, and thus of the radioactivity, is about one half the speed of the surface water.

The radionuclides produced by the weapons tests are selectively concentrated by the biota. On the islands Sr^{90} and Cs^{137} account for nearly all of the radioactivity in the plants and animals, while in the sea non-fission products such as Zn^{65} , Co^{57} , ^{58} , ^{60} , Fe^{55} , ^{59} and Mn^{54} are more abundant than the fission products. Sr^{90} - Y^{90} usually are not found in the plankton or fish and when present, only in very small amounts.

Field studies of the fate of radioactive wastes must be fully supported by carefully planned and executed laboratory experiments. Experiments such as those so successfully carried out at the Fish and Wildlife Station at Beaufort, North Carolina, and reported on here by Dr. Chipman provide the basic knowledge on the principles of accumulation and retention of radionuclides by marine life.

Contractors of the AEC operate gigantic industrial plants, e.g., the General Electric Company's Hanford Atomic Products Operation, where water of the Columbia River is used to cool the atomic piles. These establishments carry on very essential studies such as those reported on by Dr. Foster. Studies are directed toward, (1) learning more about the biological effects of radiation so that tolerance limits may be defined, (2) field studies to determine whether organisms pick up sufficient quantities of radioactive materials to suffer radiation damage, (3) field surveys to determine whether organisms which take up radioactivity and are used as food by man are safe for consumption, and (4) the very important research use of the radioactive form of an element as a "tag" to study movement and distribution of a particular element, compound or organism in a biological system.

The fate of long-lived fission products (Sr, Cs, Ru, and Ce) in fresh-water communities is under study at the Chalk River Project of the atomic energy commission of Canada. Mr. Ophel is fortunate in having a 70-acre lake in which studies of the fate of Sr^{90} may be made.

Dr. Pritchard, in discussing the problems related to disposal of radioactive wastes in estuaries and coastal waters, pointed out:

..... the starting point for any evaluation is the allowable radiation dose which the general public may receive without undue risk. Consideration must be given to the routes by which activity may return to man from the marine environment, the processes of concentration of activity from sea water into the food chain, uptake of activity by suspended silt and bottom sediments, and the physical processes of movement and dispersion.

Dr. Straub summed up the radioactive waste disposal concepts:

In the environmental release of radioactivity, consideration must be given to the total exposure or total intake. This involves the recognition of radioactivity contributed from all sources--industrial exposure, water intake, inhalation, food supply, etc. The downstream use of the hydrosphere and the base line exposure of the downstream populations may be of more importance in arriving at the permissible levels of discharge than the maximum permissible values recommended for drinking water alone.

Much careful, patient, evaluation-type of work remains to be done in the field of radioactive waste disposal. These studies will require support and, most important, people of ability. To produce the trained personnel needed schools and colleges must cross over the classic academic bars and train biologists with a broader basic education in the physical sciences.

A CONSERVATIONIST'S VIEWS ON THE NEW INSECTICIDES

Clarence Cottam, Welder Wildlife Foundation - Sinton, Texas^{/1}

Problems associated with insect control have long been with us. Ditching, draining, clearing, burning, oiling and the use of various chemicals, particularly arsenicals, have been practiced for years and all have produced problems of a greater or lesser degree. The development of highly toxic, wide spectrum, non-specific, residual insecticides has greatly intensified the problem. With the exception of a few plant products, like pyrethrum and nicotine, all insecticides prior to 1943 were inorganic materials. In 1943, DDT was the only insecticide having a high residual action. Now there are over 100 organic pesticides and thousands of formulations of these complex compounds with a still greater variety of trade names. Not only is there a much greater variety of materials, but these chemical poisons are being used for an ever increasing variety of purposes.

Chemical control agents are now being used as algicides, herbicides, fungicides, insecticides, piscicides and rodenticides. Other highly lethal chemical compounds are also being used to control mammalian predators. Private citizens, organizations, municipalities, and county, state, and federal agencies, are using them for control of flies and other insect pests, as adulticides for the control of mosquitoes, and for the control of diseases and parasites of trees and shrubs. Home owners, farmers, and ranchers use them in their gardens, lawns, farms, and pastures. They are used to control aquatic as well as terrestrial weeds. They are used in astronomical quantities on farms, orchards, range lands, and forests, and the acreages treated are increasing rapidly.

The use of airplanes for broadcasting these toxicants has greatly extended and intensified their use and has made possible routine and inexpensive treatment of large areas. Vast areas

of the public domain, including both range and forest land, are sprayed or dusted annually. Still, the most intensive use and by far the greatest quantity of pesticides applied are for protection of field, orchard, and truck crops. It has been reported that in the South the amount of technical material (i.e. without the dusts, water, oil, clay, or other carrier material) applied per acre of cultivated crops may vary from three to ten pounds annually.

In 1957, America used some 35,000,000 pounds of undiluted arsenical salts, 45,000,000 pounds of copper sulfate, 6,000,000 pounds of organic phosphates, and 130,000,000 pounds of chlorinated insecticides and fungicides.^{/2} Control agents and formulations are legion and new products appear almost weekly. Today, well over 6,000 brand-name formulations are sold over the counter, and most of these with little more restriction than the rather high price of the concoction, despite the law that pesticides must be registered and properly labelled.

Last year, a billion pounds of chemical pesticides were applied to about 100,000,000 acres of land, or about 5% of the United States. Mixed with dusts, oils, water and other solvents, emulsifiers and carriers, the volume totaled between two and three billion pounds and cost the consumer over 500 million dollars. A four-fold expansion of this program is expected within the next ten or fifteen years. Currently, more than 1/6 of our crop lands and millions of acres of forest and range lands are treated annually with pesticides in quantities of a few ounces to 25 or more pounds per acre.

The magnitude of this problem is tremendous and points to the urgent need for close cooperation between those directing the control operations and those whose interests may be affected

^{/1} Contribution #35, Series A, Welder Wildlife Foundation

^{/2} DeWitt, James B. 1958. Effects of Chemical Sprays on Wildlife. Audubon Magazine, 60(2):70-71

by the program. It suggests to me that ultimately legislative action by the Congress may be necessary to give more effective protection to man and his resources against over-zealous operations who may be inclined to rush into drastic and widespread operational eradication or control programs without necessary research to guide them. The public need of widespread control should be well determined. Knowledge needs to be available concerning the probable or possible indirect as well as the direct effect of the projected operational program.

The current widespread fire ant program of the southeast is a case in point. It is my considered opinion that this program calls for more maturity of judgment than has yet been demonstrated by those directing this irresponsible and unnecessarily damaging operation.

Many crops would be jeopardized if pesticidal protection were withheld. Wisely directed control is a part of the American life and is here to stay. However, it is not unreasonable to insist that controls be applied with understanding, judgment, and a realization of the indirect as well as the direct effects that are likely to follow. Intellectual integrity by those directing it is to be expected. An informed public will not long tolerate a procedure that is so poorly directed that it does serious or unnecessary damage to other public resources.

It has been recognized that most control chemicals are more or less toxic to vertebrates and particularly to man. Consequently, steps have been taken to afford some protection to man and his domestic animals. Under Public Law 518 of the 83rd Congress, tolerances have been established for pesticide residues in foods and produce that enter interstate commerce, and those exceeding these limits are judged unsafe for human consumption. Users of pesticides are advised to allow suitable periods of time to elapse between application and the harvesting of crops or pasturing of treated areas.

These protective measures are quite ineffective as they relate to wildlife because the poisons are placed out in wildlife habitat, and usually these poisons are placed on wildlife foods. Birds, mammals, fishes, and other wild creatures are likely to be exposed to the sprays and other forms of control agents. Water, in which aquatic forms live, and wildlife foods at times are dangerously contaminated. Consequently,

damage to fish and terrestrial wildlife often is known to be serious and extreme.

Many of the toxicants are particularly damaging to fish and other cold-blooded creatures. The poisons reach our ponds, reservoirs, lakes and streams by direct application, by drift from areas being treated, or by being washed in from treated areas. Alarming and severe kills of fish and food chain organisms are much too common in many parts of the continent--particularly in the United States. Furthermore, it has been demonstrated that these materials can and do exert a long-time effect and can wipe out entire populations of fish. The amounts of these pesticides now used and the tremendous extent of areas covered are such that they are becoming water pollutants.

These poisons are different from most conventional pollutants in that they are highly toxic; they are surprisingly stable and are not readily subject to breakdown. Furthermore, their toxicity usually is not greatly influenced by the quality of the receiving water. These toxicants compound the problem of stream pollution because they do not enter streams or lakes at just a single point (or rarely at a few points) but are washed in from extensive areas. It would seem logical to conclude, therefore, that conventional methods of waste treatment cannot successfully be used in their control. Control of these chemical compounds must necessarily be directed at the source through materials and formulations used, the amounts applied, areas treated and the method, time and frequency of application. Watershed treatment and good soil conserving practices will, of course, help to retard dangerous runoff of polluted soil which obviously carries the lethal pesticides.

In the mid and late 1940's it was found that flies became resistant to DDT, especially when DDT was used both as a larvicide and adulticide. Later it became evident that a variety of insects became resistant to a number of insecticides. A report of the Executive Board of the World Health Organization in June of 1956 states: "The conclusion was that the development of resistance of insect vectors to insecticides has become a serious public health problem. Thirty-two countries have reported insect resistance to DDT and other new insecticides. About 35 species of insects, including various types of malaria-bearing mosquitoes, show immunity to DDT in some areas of Greece, Lebanon,

Indonesia, Saudi Arabia, Panama and Mississippi. Body lice, vectors of typhus, can no longer be controlled with DDT in Korea, and five other countries report that satisfactory control is becoming difficult. Fleas, responsible for plague, are manifesting resistance in certain parts of South America. But worse still, a strain of mosquitoes that spread yellow fever has shown itself extremely resistant to DDT in Trinidad. The destruction of flies with DDT and other chemicals is no longer possible in almost all countries where these materials have been used in recent years. The new insecticides that have become available in the last three years are too few, too limited in efficiency, and too toxic."/3

The development of resistant insect strains has led to a program of research to develop many new and ever more toxic materials. Most of these have been highly toxic, wide spectrum, residual insecticides that are surprisingly stable and long lasting in effect. The wide-spread use of these chemicals has had serious effects on aquatic as well as upon terrestrial wildlife in many areas. No one knows what will be the extent of the indirect effects upon mankind, domestic and wild animals, soil organisms or aquatic life. It is well to remember that the dangers to human health and to animal life will of necessity be a delayed action and some of this probably long delayed.

Illness and death may come after long repeated ingestion or consumption of minute daily intake of poisons. There is evidence to support this. The shallow argument that all is well because we have not died yet is little comfort for those who are stricken.

Martin/3 states that "We have much experimental evidence in animals to show that any interference with the oxidative enzyme system of the fetus during the early embryonic stage of development will cause structural changes in the tissue and organs of the body, as well as a marked increase in congenital deformities. . . It has been recently discovered that the brain of a mentally sick person uses a lower than normal amount of oxygen." He adds that many of the pesticides in the fatty tissue of the body act as inhibitors of the oxygen supply to the cells. He concludes that "The physical and

mental strength of our Nation is being lowered daily by the effects of these insecticides on our body metabolism, and there is reason to believe that the effects will be increased with their future use. . ."

I believe that our past approach to the pesticide problem needs a new look. It seems to me that instead of seeking ever more toxic, broad spectrum compounds we should strive to develop materials which are selective or specifically toxic for particular insect pests that must be controlled. It is not improbable that such an approach will result in more economical and more effective control. At the same time, it will result in much greater protection for other organisms in the biota. I am convinced we have given this field of research far too little consideration. While it is probable there is still more work needed and improvements yet to be made, this general approach has proven feasible and most efficient in the control of lamprey, house rodents and mammalian predators. I understand it is also being used here at the Taft Center in the search for algicides which are specific for those algae which cause problems in the provision of a potable water supply. Some such method must be used if we are to avoid pollution of our waters and serious damage to our aquatic and terrestrial wildlife. It is no secret that insecticidal poisons have already been found, even at the mouths of many of our major river systems. With present and contemplated control and "eradication" programs for various insects and other organisms (such as the wholesale broadcasting of poisons ostensible to "eradicate" fire ants), we may be sure this pollution will rapidly increase unless more selective and wiser methods of approach are followed.

Many of these chemicals are extremely toxic to fishes. I understand that several of them have 96 hour TLm values below 10 ppb, and for endrin it is less than one part per billion. If the present trends continues, it is probable that we will get amounts of highly lethal toxicants in our streams that definitely will be limiting to some important forms of aquatic life. I trust you will agree with me that this is a field that warrants out serious and objective consideration.

/3 Martin, W. Coda. 1957. Insecticides Today and Tomorrow. Address before the 1957 N.F.A. Published in the Congressional Record of Tuesday, June 4, 1957, by the Honorable Lee Metcalf. Pages A4616-A4618.

This is an age of specialization; therefore, it is to be expected that pesticide operators would have as their objective the effective control of pest species. Experience teaches that all too often these specialized workers look for immediate effectiveness, efficiency and economy of control, without regard to other organisms in the biota. Control, when conducted with chemical agents alone, is a repetitive process and normally very costly. Consequently, such an approach is often abandoned sooner or later. Biological control, wherever feasible, has proven most satisfactory and should be the aim wherever and to whatever extent is possible. A combination of the biological and chemical approach to control, at times, is the most advantageous. Chemical controls should not be stressed over good sanitation practices and environmental control.

Those directing as well as those engaged in operational control should be well-grounded in ecology and should understand the environmental approach to these land-use problems. The environmental effects of a proposed treatment should be thoroughly studied and effects upon the entire biota well understood before launching a large scale control or "eradication" program. When such programs are initiated and directed by government, there is an added responsibility to see that the public interests of all the people are appropriately considered and evaluated. Foresight is much more difficult to attain than hindsight, but to a public-spirited, intelligent citizen, it is much more rewarding and satisfying. The Federally directed "fire ant eradication" fiasco should afford a splendid object lesson of how not to proceed to make friends, influence people or attain a satisfying degree of

success in a public service.

Our wildlife species are public property and protected by international treaty and by federal, state, and local laws and regulations. Aside from all benefits and interest in our various species, control operators, particularly government workers, have a moral obligation to protect this resource. Wildlife resources are of high economic, social, aesthetic and recreational value and certainly should be protected and wisely managed. Unnecessary destruction of valuable species should not and will not long be tolerated by an informed public. As our population increases, and especially at times like the present when it is skyrocketing explosively, the value of our aquatic as well as the terrestrial resources correspondingly increase. With increased population, pure water becomes even more of a national and individual necessity. Preservation and conservation is far better than costly restoration. Let us remember always that willful waste makes woeful want.

I do not agree with the defeatist attitude that to protect our agricultural crops we must inevitably sacrifice wildlife values. If we take a positive rather than a negative approach and develop procedures and techniques through appropriate research, I believe we can have both good crops, clean water, and wildlife. Surely we can find selective and specific pesticides which we can use to control pests without significant detrimental effects to other public values or to other members of the biota which are of high economic, social, or recreational importance. It has been done before. The possibilities are there and the promised rewards are worthy of our best efforts.

WHAT ARE THE SIDE EFFECTS OF THE IMPORTED FIRE ANT CONTROL PROGRAM?

I. B. Byrd, Division of Game and Fish - Alabama Department of Conservation,
Montgomery, Alabama

ABSTRACT

The program to eradicate the imported fire ant (*Solenopsis saevissima richteri*, Forel) is tremendous in scope. As of March 1, 1959, the U. S. D. A. Plant Pest Control Division reported that 901,351 acres of lands infested by the imported fire ant had been treated in nine southern states. Another 21,676,464 acres of infested lands are scheduled for treatment under the "1957 Plant Pest Act" as federal funds are appropriated and matched by funds from state and private sources.

The imported fire ant was introduced into the United States probably through the Port of Mobile around 1918. Although an "all out" eradication program is now in progress, the imported fire ant is considered among the twenty most important economic insects in only two states. In these two states (Mississippi and Louisiana) it is far down the list in importance and is grouped with insects affecting man and domestic animals rather than agricultural crops. Apparently, the major agricultural objection to the imported fire ant is that it builds mounds that interfere with the operation of mowers, combines, and other farm machinery. It is also considered a nuisance, particularly to hand labor on farms and it constitutes a minor hazard to children on lawns and playgrounds. According to Dr. Kirby Hayes, the imported fire ant is considered beneficial in Argentina.

As of this date, most of the treatments to control the imported fire ant have consisted of an application of twenty pounds of 10 percent granulated heptachlor or dieldrin per surface acre. These chlorinated hydrocarbons are applied by airplane, motorized ground equipment or hand applicators.

Fish and wildlife kills resulting from the fire ant eradication program have been reported from Georgia, Florida, Alabama, Louisiana and Texas. Conservationists have been most alarmed because of the tremendous values of fish and wildlife in these states. In Alabama, hunting and fishing are valued in excess of \$48,000,000 annually. Unfortunately, in Alabama alone there are still to be treated an estimated 11,098,391 acres of land infested by the imported fire ant. Studies by wildlife biologists have revealed that certain species of wildlife have been almost completely eliminated in some areas that have been treated for the eradication of the imported fire ants. Studies to date on the side effects of the eradication program have been greatly hindered because of limited personnel, equipment, and funds for fish and wildlife research. Studies to determine the effect of the eradication program on fisheries and other biotic forms including aquatic insects (fish foods) have been particularly lacking.

The program to eradicate the imported fire ant (*Solenopsis saevissima richteri*, Forel), is tremendous in scope. As of March 1959, the United States Department of Agriculture Plant Pest Control Division reported that 901,351 acres of lands infested by the imported fire ant had been treated in nine southern states. Another 21,676,464 acres of infested lands are scheduled for treatment under the "1957 Plant Pest Act" as federal funds are appropriated and matched by funds from state and private sources. In Alabama, landowners have already signed agreements for the treatment of 623,220 acres of infested lands whenever state funds are available to match federal and landowner funds.

The imported fire ant was introduced into the United States, probably through the Port of

Mobile, around 1918. Although an "all out" eradication program is now in progress, only two states, Louisiana and Mississippi, consider the imported fire ant among their twenty most important economic insects. In these two states the imported fire ant was grouped with insects which were a nuisance to man and domestic animals rather than economically important as a pest of agricultural crops (Cooperative Economic Insect Report, Plant Pest Control Division, U.S.D.A., May, 1958). The major agricultural objection to the imported fire ant is that it builds mounds that interfere with the operation of mowers, combines, and other farm machinery (Arant, Hays and Speake, 1958). It is also a nuisance to hand labor on farms and to children on lawns and playgrounds.

The imported fire ant eradication program was founded on information from individuals and from federal and state agriculture departments (Congressional Record, U.S.D.A. Leaflet 350, and official film of U.S.D.A., "Fire Ant on Trial") that several million dollars worth of damage to crops, livestock and humans resulted annually from the ant's attacks. Research in Alabama, where more than one-half of the fire ant infestation is located, tends to refute this information. Hays and Hays (1958) found from their research studies in Alabama that the fire ant seldom eats seed, seedlings, or roots of plants. When field, garden, and flower crops were planted in the mound in the laboratory, fire ants turned cannibalistic instead of eating the plant material. During their field observations they found that "at no time were the ants observed feeding on plants in their natural environment. No injury to vegetation was observed or reported except in the building of mounds". They also state, "the primary dietary item of the imported fire ant as determined by this study was insects, live insects as well as the countless dead and immature forms".

Dr. F. S. Arant, head of the Zoology-Entomology Department of the Agricultural Experiment Station at the Alabama Polytechnic Institute (private communication), stated, "Damage to crops by the imported fire ant in Alabama is practically nil. Actually, this department has not received a single report of damage to plants by ants in the past five years". Arant further stated that "Occasionally, the fire ants consume seed that are high in fat and protein content. Damage to plants in general is rare, except that resulting from building mounds. No damage to livestock has been observed. Cattle and sheep graze over the mounds and even lie down near them. Newly born livestock is rarely if ever killed."

Dr. D. G. Gill, Alabama State Health Officer, (private communication) stated, "There has never been recorded in Alabama a human death resulting from the bites of imported fire ants. The medical cases resulting from the bites of fire ants are so incidental that they are not worthy of the record."

Hays (1958) after a trip to the fire ant's native homeland, stated that farmers and entomologists in Argentina consider the fire ant to be beneficial. Studies there indicate that the insect feeds almost entirely on undesirable insect pests.

TREATMENT

When the program was initiated in Alabama in February 1958, block areas up to 20,000 acres in size received broadcast treatments with 20 pounds of granular material containing 10 percent heptachlor or dieldrin per acre. As the program progressed, emphasis was shifted to a solid treatment of cultivated fields and open lands with spot treatments where needed in the woodlands. At the present time, however, some areas are being treated by individual landowners with 2 pounds of technical chemical per acre with aerial treatment of cultivated lands, open lands and woodlands. The farmer has the option of the following alternatives in the treating of his lands:

1. To deposit one dollar with his local committee for each acre of his open land in the treatment area.

2. To apply the insecticide either as a separate operation or in connection with his other farm practices to all of his open land, the insecticide to be supplied to him by the other participating agencies.

3. To defray all expenses connected with the treatment of one-third of his open land, the other two-thirds to be treated by the other co-operators at no additional cost to him.

Cost of treatment at the present in Alabama is approximately \$3 per acre usually shared in thirds by the U. S. Department of Agriculture, State Department of Agriculture and the landowner.

EFFECTS OF THE PROGRAM ON FISH AND WILDLIFE

Fish and wildlife kills resulting from the fire ant eradication program have been reported in Georgia, Florida, Alabama, Louisiana and Texas. Mississippi is just now getting its eradication program underway and according to the U.S. D.A., all of the small infestations in North Carolina and South Carolina were eliminated in a short time. Conservationists in the five states of heavy infestations and widespread treatments have been most alarmed by the reported kills because of the tremendous values of fish and wildlife in these states. In Alabama, hunting and fishing are valued in excess of \$48,000,000 annually; nationally, the total annual value is around \$3,000,000,000. When the values apparently being sacrificed are compared with

the economic damage done by the fire ant, there is little doubt that this program should be re-evaluated.

Unfortunately, in Alabama alone there are still to be treated an estimated 11,098,391 acres of land infested by the imported fire ant. Studies by wildlife biologists reveal that certain species of wildlife have been almost completely eliminated in some areas treated for the eradication of the imported fire ant. Studies to date on the side effects of the eradication program have been greatly limited for lack of personnel, equipment, and funds for fish and wildlife research. Studies to determine the effects of the eradication program on fisheries and other biotic forms including aquatic insects (fish foods) have been particularly lacking.

Research on the 3,600-acre Camden area in Alabama (Baker, 1958; Speake, 1958; Clawson, 1958; Clawson and Baker, 1959) revealed that treatments to control the imported fire ants caused heavy mortality to wildlife. Fish and other aquatic life were also killed. The entire area was treated (except for portions of beaver ponds) at a rate of 2 pounds per acre of dieldrin or heptachlor. Clawson and Baker (1959) indicated that the average rate of application may have been less than 2 pounds per acre. All resident quail, 13 coveys, disappeared from the area. The only survivors were among two coveys ranging to a large extent off the treated area. During the same period, only two quail disappeared among 8 coveys on a 600-acre untreated check area. All specimens autopsied contained sufficient dieldrin or heptachlor to attribute death to the insecticide. One covey of 10 quail was observed almost daily until the entire covey was gone. Half of these birds were picked up dead or moribund. Of all quail originally on the treated area, 17 percent were recovered as dead or dying birds.

Alabama Department of Conservation personnel (News release, 1958) reported that on a tract of 10,000 acres treated in Autauga County, Alabama, a check of a 10-acre strip of woods and hedge rows seven days after treatment with 20 pounds per acre of 10 percent heptachlor revealed 6 rabbits, 3 quail, 3 opossums, 1 raccoon, 1 barred owl, 10 cardinals, 20 song sparrows, 2 blue jays, 1 mocking bird, 1 brown thrasher, 1 warbler, 1 red-breasted woodpecker, 2 cotton rats and 1 white-footed mouse in a dead or dying conditions. In a drainage ditch which

traversed the area numerous dead or dying fish and frogs were observed. From studies in Louisiana, Glasgow (1958) stated that the initial wildlife mortality following the application of 2 pounds of active heptachlor per acre was high. Nestling mortality was severe. Red-winged blackbirds and meadowlarks were reduced to zero on the study area. Several specimens of birds and animals found dead on the study areas and submitted to the Patuxent Research Laboratory, U. S. Fish and Wildlife Service contained heptachlor. Earthworms which are the chief food of woodcock contained heptachlor 5 months after treatment. These worms may constitute a hazard to all ground feeding birds. In addition, the Louisiana check showed that initial application of heptachlor reduced the earthworm population 78.9 percent.

In Georgia, 6 quail, 7 rabbits, 20 song birds, 3 field rodents, and 1 cat were found dead on a 2-acre plot which had been treated with heptachlor at 20 pounds of 10 percent chemical per acre (Jansen, 1958). Analyses of these specimens revealed heptachlor in body tissues. Bird and animal activity in this area was appreciably lower than in adjacent untreated plots. A later check of the treated area revealed no live birds or rodents.

Texas studies (Lay, 1958) on the Fralise Ranch, where heptachlor was applied at the rate of two pounds per acre, revealed that:

1. Bird populations along ranch roads in the treated area were reduced 92 to 97 percent in two weeks.
2. Bird populations within acre-plots studied were reduced 85 percent in two weeks.
3. Nestling success of birds in the area was reduced 89 percent.
4. Almost all wildlife species present--including birds, mammals, fish, reptiles, amphibians, insects and crustaceans--were affected.
5. Heptachlor proved to be lethal to wildlife when applied to either wet or dry soil.

It was reported from Florida (Wisenhunt, 1958) that residents of Milton and Jay in Santa Rosa County suffered losses of cats, dogs, fishermen's worm beds, song birds, and chickens. They attributed their losses to the treatment of their cities for fire ants.

About 700 acres of Boys Industrial School lands near Marianna, Florida, in Jackson County were treated with dieldrin by ground application at the rate of two pounds of insecticide per acre. Almost immediately after the application dead fish, birds, mammals, and amphibians were found on the area.

Much too little is known about the side effects of the imported fire ant treatments on fish, wildlife and other biotic forms, because of the lack of funds and shortage of personnel. The rush with which the eradication program was initiated gave little opportunity for desired research. Dieldrin and heptachlor are generally considered to be 10 to 20 times more toxic than DDT. Probably more information is available on the effects of DDT on fish and wildlife than of any other of the chlorinated hydrocarbons and its toxicity to fish and wildlife is quite "staggering". However, published reports on the effects of the new chlorinated hydrocarbons on fish and wildlife have been most alarming.

Montana Fish and Game Department Biologists observed heavy fish mortality throughout drainages of the Helena and Nez Perce National Forests in 1953 and 1955 after treatment with DDT for the control of spruce budworm (Gabrielson, 1958). Six hundred whitefish, brown trout, and suckers were found dead on one 250-yard stretch of the Yellowstone River. In some streams fish populations were reduced by about 84 percent below pre-spraying levels.

The extreme toxicities of most of the chlorinated hydrocarbons to fish have been reported by numerous authors. (Tarzwell and Henderson, 1957; Tarzwell, 1959; Henderson, Pickering and Tarzwell, 1959; Surber, 1951; Fielding and Baldwin, 1955 et al.). George (1957) summarized many of the toxicity studies of chlorinated hydrocarbons relating to both game and fish.

An application of 1 pound of dieldrin per acre killed an estimated 1,175,000 fish weighing 20 to 30 tons and almost all of the crabs in a 200-acre marsh (Herrington and Bidlingmayer, 1958). Some bird losses occurred at 0.2 pound treatment of dieldrin per acre (Ginsburg and Jobbins, 1954); a 0.5-pound-per-acre treatment of dieldrin killed large numbers of water birds and a smaller number of upland game birds (Rudd and Genelly, 1956).

DeWitt (1955) found that breeding quail fed a diet containing .001 percent dieldrin for a total of 10 weeks produced the same number of fertile

eggs during the first four weeks, but that hatchability dropped from 87 percent to less than 42 percent. Most of the chicks that survived for more than 3 weeks in his studies were produced from eggs laid during the first 2 weeks after feeding of the insecticide was started.

Genelly and Rudd (1956) maintained ring-necked pheasants on diets of 200 ppm. and 100 ppm. of dieldrin. Six out of 10 females at 200 ppm. died within 28 days, and 5 out of 10 females at 100 ppm. died within 38 days. The only male tested at 25 ppm. died while 21 females survived.

OTHER EFFECTS OF THE IMPORTED FIRE ANT CONTROL PROGRAM

Peters (1958) reported that when the chlorinated hydrocarbons are applied as in the fire ant program, insects are the first organisms to be killed - which may be within a few hours after application. He further states that beneficial insects are killed during every application of poison.

Heavy losses of bees in the treated areas have caused great concern on the part of beekeepers. Alabama beekeeper W. H. Harrell, in a report verified by Alabama Polytechnic Institute entomologists, set his loss at about \$3,000. Another beekeeper, J. H. Moody, stated in an affidavit that he lost almost \$8,000, although his bees were in perfect condition before the chemicals were applied in the area of his hives (Jerry Teer, *Montgomery Advertiser*, Jan. 22, 1959).

Livestock in some instances have suffered severe damages. Ranchers and farmers in Decatur County, Georgia, sought damages from the Federal government for loss of some 100 head of cattle and the complete lack of reproduction in 100 brood sows following application of chlorinated hydrocarbons (Alabama Department of Conservation News Release, 1958).

Affidavits by home owners in Monroeville, Alabama, state that at thirty-six homes in the area, the kill included 697 chickens, 20 turkeys, 11 cats, 2 ducks and more than 50 dogs hauled to the city dump (Jerry Hornsby, *Alabama Journal*, October 30, 1958).

Farmers in Lafayette Parish, Louisiana, sought relief from the state for losses sustained from the sugar cane borer, claiming that hepta-

chlor applications for fire ant control had killed natural controls of the sugar cane borer allowing it to increase in abnormal numbers (Daily Advertiser, Lafayette, March 3, 1959).

CONCLUSIONS

The writer agrees with Dr. John L. George (1958) that surprisingly little is known about

the biology or economic effects of the imported fire ant to be committed to an all-out eradication program, especially when important fish, wildlife and other values are so deeply involved. Much additional scientific work is also needed to evaluate the effect of the imported fire ant eradication program on fish, wildlife, and all other biotic forms.

REFERENCES

- Arant, F. S., Kirby L. Hays and Dan W. Speake. 1958. Facts about the imported fire ant. Highlights of agricultural research, 5 (4).
- Baker, Maurice F. 1958. Observations on effects of an application of heptachlor or dieldrin on wildlife. Proc. Southeastern Assoc. Game and Fish Commissioners, (1958): (In Press).
- Clawson, Sterling G. 1958. Fire ant eradication and quail. Ala. Conserv. Dec. 1958 - Jan. 1959. pp. 14-15.
- Clawson, Sterling G., and Maurice Baker. 1959. The immediate effect on bobwhite on an application of dieldrin or heptachlor. Jour. Wildlife Mgt., 23 (2) (In Press).
- DeWitt, James B. 1955. Effects of chlorinated hydrocarbon insecticides upon quail and pheasants. Agricultural and Food Chemistry, 3 (8):672-676.
- Fielding, James R. and W. P. Baldwin. 1955. Effect of some new insecticides on fish and wildlife. Pesticides Handbook: pp. 84-99.
- Gabrielson, Ira N. 1958. Pesticides, blessing or curse? International Association of Game, Fish and Conservation Commissioners, (In Press).
- George, John L. 1957. The pesticide problem. Conservation Foundation. 57 pp.
- George, John L. 1957. The program to eradicate the imported fire ant. Conservation Foundation. 39 pp.
- Ginsburg, J. M. and D. M. Jobbins. 1954. Research activities on chemical control of mosquitoes in New Jersey in 1953. Proc. New Jersey Mosquito Exterm. Assoc., 41:279-291.
- Glasgow, Leslie L. 1958. Studies on the effect of the imported fire ant control program on wildlife in Louisiana. Proc. Southeastern Assoc. Game and Fish Commissioners, (1958): (In Press).
- Harrington Jr., Robert W. and William L. Bidingmayer. 1958. Effects of dieldrin on fishes and invertebrates of a salt marsh. Jour. Wildlife Mgt., 22 (1):76-82.
- Hays, Kirby L. 1958. The present status of the imported fire ant in Argentina. Jour. of Economic Entomology 51 (1): 111-112.
- Hays, Sidney B. and Kirby L. Hays. 1958. Imported fire ant. Ala. Poly. Inst., 11 pp. (Mimeo.)
- Henderson, C., Q. H. Pickering and C. M. Tarzwell. 1959. The relative toxicity of ten chlorinated hydrocarbon insecticides to four species of fish. Trans. Am. Fish. Soc., 88: (In Press).
- Jansen, D. H. 1958. Effects of the fire ant eradication program upon wildlife. Bureau of Sport Fisheries and Wildlife, U. S. Dept. of Interior, 7 p. (Mimeo.)
- Lay, Dan. 1958. Count three for trouble. Texas Game and Fish. July pp. 4-7.
- Peters, Harold. 1958. You are being stung? Florida Wildlife, Nov. pp. 4-5.
- Rudd, Robert L. and Richard E. Genelly. 1956. Pesticides: their use and toxicity in relation to wildlife. Calif. Dept. of Game and Fish. Game Bull. No. 7., 209 pp.
- Speake, Daniel W. 1958. Fire ant eradication and fire ants in Alabama. In The effects of toxic pesticides on wildlife, 54th Annual Conf. Nat. Audubon Soc., pp. 4-7.
- Surber, E. W. 1951. Toxicities of some chemical substances to fish. Manuf. Chem. Assn. Sixth Ann. Pollution Abatement Conf. 16 pp.
- Tarzwell, Clarence M. 1958. The toxicity of some organic insecticides to fishes. Proc. Southeastern Assoc. Game and Fish Commissioners, (1958): (In Press).
- Tarzwell, Clarence M. 1959. Pollution effects of organic insecticides. Trans. N. Am. Wildlife Conf., 24: (In Press).
- Tarzwell, Clarence M. and Croswell Henderson. 1957. Toxicity of dieldrin to fish. Trans. Am. Fish. Soc., 86: 245-257.
- Wisenhunt, Matt. 1958. The fire ant eradication program and wildlife in Florida. Florida Wildlife. Nov. pp. 5.

ARE THE INSECTICIDES REQUIRED FOR INSECT CONTROL HAZARDOUS TO AQUATIC LIFE?

Clarence H. Hoffmann - Entomology Research Division, Agricultural
Research Service, U.S. Department of Agriculture, Beltsville, Maryland

ABSTRACT

Insects are probably man's greatest challenge to supremacy on earth. In the United States there are about 10,000 injurious species and in spite of many effective control measures they cause losses of about four billion dollars annually. DDT and other synthetic organic insecticides have saved millions of lives by controlling insects that carry diseases, have greatly increased the yields and quality of crops, and have saved forests from destruction from insects. The quantities required are increasing each year, about 569,927,000 pounds being produced in 1956. Large quantities of these insecticides are dispersed from airplanes. It is the widespread use of insecticides that concerns the public because of their potential hazard to health and of damage to fish and wildlife.

A review of the literature with special reference to the adverse effects of the chlorinated hydrocarbon and organic-phosphorus insecticides on aquatic life indicates only minor losses in comparison with the vast quantities used annually. Other factors in land use and development appear to be more damaging than insecticides. Some losses attributed to insecticides may be due to misuse and cleaning of spray equipment in ponds and streams. Most of the large-scale spray operations are under the supervision of competent Federal and State authorities, who have carefully weighed the economic benefits of controlling or eradicating serious pests against other values, including those associated with water resources.

There is real need to advise the public on large control programs well in advance so that they will be properly informed as to aims, nature of operations, benefits, and hazards. Close cooperation and trust between officials of different agencies and disciplines is required to insure that all interests are adequately protected. A fish kill, whether

small or inconsequential in terms of the total population in a lake or stream, will make the headlines, and if there is no readily explained cause it is often blamed on the use of insecticides. Even some representatives of wildlife organizations appear to be ill informed on objectives and merits of current insect-control programs and also on research findings made several years ago from toxicological studies of DDT in relation to human health and also to fish and wildlife.

The Entomology Research Division recognizes the benefits and limitations of different control methods and is striving to meet the most urgent problems with available resources. Research is being undertaken on biological control, the development of additional crop varieties resistant to insect attack, possible use of hormones and growth-inhibiting substances as control agents, new ways to use insecticides such as baits with attractants, systemic insecticides that are specific against certain insects, and the continued release of males sterilized by gamma rays from a cobalt-60 source to destroy the reproductive potential of natural populations of insects.

With the expanding use of insecticides there is a marked need for broad and detailed cooperative studies between entomologists, fishery biologists, and chemists to determine the direct and longterm effects on aquatic life of insecticides in current use and those expected to be used in future control programs. Of significance is that preliminary laboratory experiments indicate that a number of the organic phosphorus and carbamate insecticides are less toxic to fish than some of the chlorinated hydrocarbons. Studies thus far on the effects of insecticides on fish-food organisms are limited almost to DDT. There is a dearth of information from field studies, which are essential for a practical evaluation of each insecticide and its effects on aquatic life.

It is a pleasure to participate in this Second Seminar on Biological Problems in Water Pollution. Such a seminar permits the workers in various scientific fields to become better acquainted and to plan future cooperative research utilizing improved techniques and new approaches to solve problems which center about one of our most important natural resources--water. Currently pesticides, particularly insecticides, are being condemned by some individuals and

organizations purportedly because of the damage they cause to human health, crops, livestock, fish, and wildlife. As with any controversial issue, it is only fair to review both sides carefully and to evaluate programs in terms of the greatest benefit to the public. There is an important need for administrators and scientists primarily concerned with research and pest-control programs to get together more frequently with their associates who are devoting

their primary effort to protecting public health, fish, and other values to consider these problems and proper courses of action. Even though the subject matter is broad and complex and involves several interests continued progress will be made by considering factual information in an atmosphere of frank and unemotional discussions.

All of us are responsible for encouraging the intelligent use of land and water. From the viewpoint of public health and fish and wildlife resources, serious water pollution may result from (1) the shift in land usage, including the change from hilly land most suited for pastures and forests to cultivation and consequent siltation in streams; (2) industrialization which may contaminate streams through improper treatment of chemicals before discharge; (3) silt and washings from mining operations; (4) discharge of radioactive wastes; and (5) expanded urbanization with attendant problems of disposal of raw sewage and household detergents. Some of these changes have had a drastic effect on wildlife habitats. They have been going on for a long time and are inherently a part of civilization. Hence it becomes nonsensical to talk about maintaining a complete balance of nature, because through man's activities these disruptions are becoming increasingly more the rule. Nevertheless, we should do what we can to keep these undesirable changes to a minimum. Actually, of course, natural habitats are subjected continuously to major upsets. Lately the widespread use of insecticides has come in for some criticism as a water pollutant, and it is timely to review this matter since all of us have an abiding interest in clear and clean waters and in the preservation and harvest of fish and wildlife depending on the species. Entomologists, in response to grower and public demand, have the responsibility for developing and recommending ways to control destructive insects. The most feasible approach for dealing with insect problems has been the use of insecticides. The problem immediately resolves itself in the selection of insecticides that are the most effective against destructive insects and at the same time the least hazardous to other organisms.

For several years I had an opportunity to study the side effects of applications of DDT over forests on both terrestrial and aquatic insect populations. It was soon determined that the dosage used the greatest potential hazard was to aquatic organisms, and accordingly

studies were intensified on streams and lakes. In this paper I plan to review the studies made on the effects of insecticides on aquatic life in this country since Rudd and Genelly (1956) published their bulletin entitled "Pesticides: Their Use and Toxicity in Relation to Wildlife." Incidentally, these authors arrived at the general conclusion that pesticides were less harmful to fish and wildlife than were changes brought about by land and water development and use. Their bulletin revealed that few extensive experimental studies have been made to determine the effects of various insecticides on stream fauna. The few recorded losses to fish and aquatic birds were largely associated with the misuse of insecticides, such as cleaning of spray equipment in ponds or streams or their use on an emergency basis. Such was the record up to 1955 in relation to the treatment of millions of acres of crops, forests and swamps that had been successfully sprayed during a 10-year period to control serious pests without permanent damage to fish and wildlife resources. Later in this paper I will summarize the results of research investigations and reports of damage to aquatic life resulting from insecticide applications since 1955.

Benefits of Insect Control

Before considering the potential hazards of insecticides to aquatic life, it seems appropriate to review the need for control materials. It is easy to forget that insects are probably man's greatest challenge to supremacy on earth. It is estimated that in the United States 10,000 species are injurious and in spite of many effective control measures they cause losses of approximately \$4,000,000,000 annually. If control measures were not available, the annual losses would exceed this figure by several times. In fact, many crops could not be grown economically and our standards of health and economy would suffer serious setbacks. Insects are, therefore, of great economic importance and have a direct or indirect effect on each citizen. Entomologists welcomed the availability of DDT in 1942 for the control of insect-borne diseases threatening military and civilian lives, which historically have been greater killers of man than the instruments of war. Knipling (1953) estimated that during the first 10 years of use 5 million lives were saved and 100 million illnesses prevented through the use of DDT for controlling such diseases as malaria, typhus, and dysentery. The World Health Organization

states that in at least 120 of about 200 countries and territories of the world malaria acts as a drag on economic development. Largely through the use of modern insecticides for mosquito control, progress is being made to eradicate malaria on a world-wide basis.

Following the war DDT and other chlorinated hydrocarbon insecticides became available for civilian use. Within a few years outstanding control was obtained against insects that damage or destroy fruits, vegetables, tobacco, sugar beets, sugarcane, cereals, cotton, pastures, ornamentals, and livestock. Soon the yields of many crops jumped 10 to 20 percent or more, and they were of higher quality. Moreover, some of these new materials were effective against insects that carry destructive diseases of plants, livestock, and man. Crop losses caused by many pests were reduced drastically. This is the background that led to the great dependence being placed on the use of insecticides. They have become a way of life and most assuredly will be recommended and used until such time as other control measures are developed. The insecticide recommendations of the Entomology Research Division (1959) for the control of insects attacking crops and livestock are given in a 129-page handbook, which also includes a discussion of precautions, including safeguards in relation to fish and wildlife and individual safety restrictions to protect spray applicators, and also restrictions on the timing of applications in reference to harvest in order to meet tolerances established by health officials.

Forest insects, the greatest single hazard to forest crops, are estimated by the Forest Service to be responsible for 40 percent of all the losses of saw timber and 28 percent of those of growing stock. Forests must be protected from insects if we are to have (1) lumber and other wood products; (2) clean water for irrigation and hydroelectric power and to fill industrial and domestic water needs; (3) meadows and grasslands for the grazing of domestic livestock and wildlife; (4) suitable habitats for fish and wildlife sought by some 30 million fishermen and hunters; and (5) scenic areas for camping, vacationing, and recreation. Until DDT was found to be effective against defoliating forest insects when dispersed by airplane over vast and inaccessible areas, it was not possible to protect these values. Since 1945 approximately 19 million acres of forest land in the United States have been sprayed with DDT. Those so

concerned over the temporary and minor effects on fish and wildlife and their food organisms might well pause and reflect on the real damage that occurs to wildlife habitats when insect epidemics run their devastating course, which is usually followed by fire and consequent losses of timber, habitat, fish, and wildlife.

Expanded Use of Insecticides

The outstanding benefits obtained through the judicious use of insecticides led to the development of new materials and an overall increase in quantities used. You are doubtless familiar with the high grade standards maintained in this country with respect to food. The food producer must come up with products that are free not only of insect damage or contamination but also of undesirable pesticide residues. Frequently the margin of safety in either direction is very narrow. As long as we have the free enterprise system in this country, farmers and other producers will seek and use all methods of modern technology available for efficient production. If the farmer is to remain in business, he cannot tolerate insect losses to his crops.

The American public also expects complete protection from debilitating or deadly diseases, many of which are transmitted by insects, mites, and ticks. Moreover, since it has more leisure time to spend in recreational areas, there is a demand for control of such pests as mosquitoes, biting flies, ticks, chiggers, and caterpillars dropping on webs from trees. Therefore, many control programs are undertaken each year because of insects causing economic damage or becoming a nuisance.

In the United States the production of inorganic pesticides has remained fairly constant in recent years--about 450 million pounds annually, nearly two-thirds of which is ground sulfur. The production of synthetic organic chemicals has increased steadily, and in 1956 amounted to 569,927,000 pounds valued at the producer level at \$274,894,750 (Shepard 1958). In 1955 it was estimated that pesticide costs averaged about \$60 per farm. There has been a growing use of airplanes to disperse chemicals. In 1956 approximately 38,667,000 acres of crops, forests, and other land were treated from the air for control of insects. In 1957 the production of some major insecticides was about as follows (in pounds): aldrin, chlordane, dieldrin, endrin, heptachlor, and toxaphene (combined)

75,000,000; BHC exclusive of lindane 46,000,000; calcium arsenate 20,000,000; DDT 124,000,000; and lead arsenate 13,000,000.

According to Metcalf (1959), there are approximately 40 organic-phosphorus pesticides in commercial or semicommercial use on a world-wide basis. His estimates of world production having an annual value of \$50,000,000 are as follows (in pounds): parathion and methyl parathion 20,000,000; malathion 10,000,000; Diazinon 1,000,000; Trithion 1,000,000; Guthion 1,000,000; Systox and Meta-Systox 500,000; TEPP 400,000; Phosdrin 250,000; schradan 100,000; and Thimet 100,000.

These figures on insecticide production serve to point out those materials that are being used most widely. There is no question but that large quantities of insecticides will continue to be used. As some fail because certain insects become resistant to them or for other reasons, new ones will become available. Increasing interest is being shown in nonchemical methods of insect control, involving biological control agents, plant varieties resistant to insect attack, and other methods. There is reason to believe that with adequate research support such methods can be developed that will solve many of our major pest problems, and thus avoid many of the hazards. To be realistic, however, we must recognize that insecticides will be needed to meet insect problems for many years to come. It is essential, therefore, that major emphasis be given to research on the development of chemicals and methods for their use that will provide satisfactory control with minimum hazard to other organisms. Through cooperative studies by specialists of various disciplines I personally feel confident that great progress can be made in solving the many complex problems associated with the use of insecticides and their hazards to fish and wildlife, and that sound recommendations can be made that will be satisfactory to all, as was done in the cooperative studies on DDT.

EFFECTS OF CHLORINATED HYDROCARBON INSECTICIDES ON AQUATIC LIFE

Much publicity has been given to a substantial fish kill several months after the spraying in 1955 of forest land near the Yellowstone River in Montana. Because there was no evident cause, this fish mortality was attributed by some to DDT spraying at the rate of one pound per acre

for control of the spruce budworm. Because there was no mortality of fish at the time of spraying (Parker 1956), and of the distance of the forest from parts of the river, it is hardly conceivable that DDT could have been the cause of such delayed mortality of large fish (Hoffmann 1958, Hoffmann and Drooz 1953, Cope and Springer 1958).

Cooperative studies made on 13 smaller streams in this area in 1956 by the U.S. Forest Service, the U.S. Fish and Wildlife Service, and the Montana Fish and Game Department (Graham and Scott 1958) confirmed previous findings in the East that aquatic insects were materially reduced by the DDT spray dispersed at 1 pound per acre. Most of the trout gorged on insects killed by the spray but did not succumb, there was a gradual repopulation of aquatic insects during the 4 months after spraying, and no indication of leaching of DDT into one stream after a 1.2-inch rainfall. Other findings of note were: (1) numerous yearling brook trout collected in one stream a year after treatment showed survival of young-of-the-year fish; (2) live brook trout captured 16 months after spraying were found to contain DDT; and (3) trout in a sprayed stream where the bottom fauna was depleted fed on terrestrial insects and midge fly larvae. In 11 of these streams, in which maximum damage would be anticipated, there was no delayed fish mortality, but in two of them game-fish reductions of about 70 and 80% were found in certain sections which may have been due to delayed effects of DDT.

In 1957 I had an opportunity to visit this area and to confer with specialists in the cooperating agencies, and also with others of the zoology and chemistry departments of Montana State College, in regard to setting up an intensive study of the effects of DDT spraying on fish and fish-food organisms in the Ruby River. M.S. Schechter, chemist of our Pesticide Chemicals Research Branch, later joined the group to assist in setting up a laboratory for running DDT analyses. A special effort will be made in this study to determine the amount of DDT in the water, sediment, vegetation, and fish both before and at intervals after spraying; direct and indirect effects of DDT on fish and fish-food organisms; and the reason for greatly delayed mortality of fish if this should occur.

For many years State and Federal officials in several northeastern States have checked

streams in connection with spray programs for evidence of fish mortality which might be attributable to the one-pound-per-acre dosage of DDT for control of forest insects. Only infrequently have sizeable losses been noted. In 1957 a number of streams were routinely checked in connection with the gypsy moth spray program, and trained workers were unable to substantiate the losses claimed by some individuals and publicized in newspaper and magazine articles.

The effects of DDT on fish and their food received considerable attention in the court case instigated in 1957 by 14 plaintiffs from Long Island, New York, to restrain the Secretary of the U. S. Department of Agriculture and the State Commissioner of Agriculture and Markets from committing trespasses upon their lands by means of low-flying planes and spraying their lands with DDT and to prevent future aerial spraying of their lands with insecticides. About 50 witnesses testified at this trial, which lasted almost a month and included testimony on the effects of DDT on human health, fish, wildlife, bees, biological control agents, plants, and soil. In his overall decision in favor of the defendants, Judge Bruchhausen (1958) stated:

"The plaintiffs have not sustained their claim that spraying causes any considerable loss of birds, fish, bees, and insects. Only a few fish and birds were killed in the subject area. Furthermore, evidence of spraying programs throughout the country demonstrates that the fish, bird, and bee loss has been inconsequential.

"While there is no evidence of damage to bees and aquatic insects in the subject area, experts and others from various sections of the country established that the defections are made up by repopulation in a short space of time."

In 1955, 0.24 pound of gamma BHC per acre in a wettable-powder suspension was applied from an airplane on a fresh-water lake in Florida to control immature stages of May flies. The obnoxious swarms of the adults caused local residents to declare they would give serious consideration to selling their homes and moving away unless relief could be obtained. The insecticide treatment was completely effective in killing the May fly nymphs and apparently had no effect on fish or other aquatic life (Lieux and Mulrennan 1955).

A detailed field study was made in 1955 in

Delaware to determine the effect on wildlife of Strobane and other insecticides used for mosquito control on tideland areas (George, Darsie, and Springer 1957). Gamma BHC, DDT, and Strobane in oil solution were applied simultaneously by airplanes to similar habitats at the rates of 0.1, 0.2, and 0.3 pound per acre. There was no significant difference between deaths of estuarine fish and blue crabs occurring in treated and control plots, or among the three treatments. Both field observations and crab-pot counts showed that the fish and blue crabs avoided areas of high insecticide concentration. However, the marsh fiddler crab was greatly reduced in numbers by all three toxicants.

A hazardous food chain relationship has shown up in connection with the treatment of Clear Lake in California with TDE to control the Clear Lake gnat, a serious nuisance to residents and to tourists who enjoy vacationing and the excellent fishing on that lake. Our Division had an important part in developing the use of TDE for almost complete control of this pest with no apparent damage to fish, which was considered an outstanding accomplishment. Now, according to Rudd (1958), repeated treatments of the lake may be the indirect cause of the death of hundreds of grebes. A fat sample from one bird showed a high concentration of TDE. Samples of visceral fat from several species of fishes taken six to eight months after the last spraying showed from 40 to over 2,000 p. p. m. of TDE. The herbivorous species of fish had the lowest concentration and the predaceous species the highest. Studies are under way to determine whether diatoms and algae and their planktonic animal feeders also contain the chemical. Further investigation may reveal the full story of this apparent long food-chain reaction, which seems almost fantastic in view of the small amount of insecticide required to control the gnat.

In August 1958 the Entomology Research Division and the Plant Pest Control Division of the U. S. Department of Agriculture and the Bureau of Sport Fisheries and Wildlife of the U. S. Fish and Wildlife Service cooperated in field studies to determine the effects of aldrin, toxaphene, and heptachlor sprays used for control of grasshoppers on aquatic life in streams within the treated areas. Results will likely be published by the Fish and Wildlife Service.

Some limited field observations on the effect of heptachlor on aquatic life have been made in

connection with the imported fire ant eradication program. In Hardin County, Texas, 1,400 acres were treated with granular heptachlor at the rate of two pounds per acre. Canal banks were hand-treated to protect fish, but some of the insecticide blew into the canals. As recorded by Lay (1958), fish and other aquatic forms were still dying 14 days after treatment. Though some live fish and crayfish were present in cages, seining indicated smaller populations than in pretreatment samples.

In 1958, in cooperation with the Plant Pest Control Division, R. A. Hoffman of this Division, made some incidental observations on fish in a 900-acre area in Montgomery, Ala., treated for imported fire ant eradication in which the pasture portion contained a shallow 1/6-acre pond and a deep (maximum 6 feet) 2-1/2-acre farm pond, both with warm-water game fish (unpublished). The pilot endeavored to avoid direct treatment (heptachlor granules at 2 pounds of heptachlor per acre) of the large pond but not the smaller one. Much of the land drained into the large pond. Dead fish, mostly stunted bluegill sunfish, were found on the surface of the shallow pond, but none in the deep pond.

Early in April 1959 representatives of the Entomology Research Division and the Plant Pest Control Division, Fish and Wildlife Service, Public Health Service, Alabama Departments of Conservation and Agriculture, and the Alabama Agricultural Experiment Station, met to consider plans for cooperative studies to determine the effect of insecticides used to eliminate the imported fire ant on a large area basis, on fish and wildlife, their food-chain organisms, water contamination, and beneficial insects.

Harrington and Bidlingmayer (1958) made a detailed study of the effects of dieldrin on fish and invertebrates in shallow ditches within a 2,000-acre salt marsh in St. Lucie County, Florida. The county government had resorted to the use of an airplane application of dieldrin granules at the rate of a pound of toxicant per acre to eliminate sand fly larvae, the adults of which cause almost unbearable annoyance to people living near marshes. The fish kill was very heavy, and by extrapolating data from the two ditches, the authors estimated that 20-30 tons of about 30 species were killed. However, by the fourth week after spraying there was an increase in killifishes and by the eighth week some species were abundant. Mollusks appeared

unharmed by the spray, but crustaceans and crabs were virtually eliminated.

In 1954 a cooperative study was undertaken by the Department of Agriculture and the Public Health Service to determine the toxicity of run-off waters from hospital grounds treated with dieldrin at the rate of 4-2/3 pounds per acre to control white-fringed beetles. Bioassays of run-off water following the first rain after treatment, which drained from the grassy slope into a storm sewer, showed it to be toxic to fathead minnows at a dilution of 1 to 3 (Tarzwell and Henderson 1957). The run-off was estimated to contain 0.128 p.p.m. of dieldrin. Apparently there was no opportunity for the insecticide diluted by rain to pass over untreated soil before reaching the storm sewer.

A recent laboratory study (Tarzwell 1958) provides information on the comparative toxicity of several chlorinated hydrocarbon insecticides to fathead minnows, bluegills, goldfish, and guppies. Under standardized conditions, including hard water and a temperature of 25°C., the 96-hour median tolerance limits (concentrations in water that kill 50 percent of test fish) for fathead minnows were as follows (p.p.m.): Endrin 0.0013, toxaphene 0.0051, dieldrin 0.016, aldrin 0.028, DDT 0.034, methoxychlor 0.035, heptachlor 0.056, lindane 0.056, chlordane 0.069, and BHC 2.0. Endrin, toxaphene, and dieldrin were the most toxic.

Except for DDT, little is known about the effects on fish and fish-food organisms of chlorinated hydrocarbon insecticides that have been used for a number of years. There seems to be a lack of information on this subject for the chlorinated miticides including Aramite, Kelthane, Dimite, Neotran, ovex, and Sulphenone. No information is available on new chlorinated hydrocarbon insecticides such as Shell SD-4402.

EFFECTS OF ORGANIC-PHOSPHORUS INSECTICIDES ON AQUATIC LIFE

Prior to the first aerial spray application in 1956 of 2 pounds of 25% malathion wettable powder plus either 1 pound of yeast hydrolysate or 1 quart of sauce base No. 2 in 1 gallon of water per acre, the formulations used to eradicate the Mediterranean fruit fly from 800,000 acres in Florida, L. F. Steiner of this Division conducted some toxicity tests with fish in concrete ponds (unpublished). He found no mortality

of tropical fish, including black mollies, yellow wags, rosy barbs, blue moons, flag fish, helleries, and red moons, at 0.15 to 0.80 p.p.m. or of marble mollies and black moons at 1.60 p.p.m. There was some mortality of liberty mollies at 1.20 and 2.0 p.p.m. Rosy barbs and yellow crescents survived 1.20 p.p.m. and dwarf gouramis and helleries 2.0 p.p.m. Field observations showed that in certain areas, especially in shallow water, considerable numbers of killifishes and certain other species were killed by these sprays (Cope and Springer 1958). There was also some loss of tropical fish but the fish losses were considered minor in relation to the large spray area and the need for repeated spraying until the Medfly was eradicated. It is regretted that fish and wildlife specialists were not available to make studies in connection with this large action program.

Henderson and Pickering (1958) made bioassays on ten organic-phosphorus compounds to determine their comparative toxicity to fathead minnows and bluegill sunfish. In general the pH and hardness were found to have little effect on toxicity. The 96-hour median tolerance limits for fathead minnows (2 to 2.5 inches) were as follows (p.p.m): EPN 0.20, para-oxon 0.33, parathion 1.4, TEPP 1.7, Chlorthion 3.2, Systox 3.6, methyl parathion 8.3, malathion 12.5, OMPA 121, and Dipterex 180. Furthermore, most of these insecticides were found to be less hazardous to aquatic life than many of the chlorinated hydrocarbons.

In Oregon the effects of three phosphorus insecticides on 8- to 10-inch rainbow or eastern brook trout were tested by introducing the solubilized or aqueous solutions by a drip method in hatchery troughs to simulate their use for control of mosquito larvae in irrigated pastures or rice fields. (Hoffman 1957). Parathion caused no mortality at 0.05 and 1.0 p.p.m. over periods of 14 and 28 hours; mosquito larvae are killed with 0.01 p.p.m. Dipterex caused no mortality of fish at 1 and 10 p.p.m. for 72 and 24 hours; it is effective as a larvicide at 0.2 p.p.m. Phosdrin caused complete kills of trout at 0.05 p.p.m. and higher.

W. G. Bodenstein of this Division has made some bioassays with phosphorus materials on the Mummichog killifish (Fundulus heteroclitus macrolepidotus) (unpublished). He used 2-gallon aquaria and introduced five fish per test in 6 liters of brackish water containing a salt concentration of 4-5 p.p.m. The temperature of the

water ranged from 21° to 26°C., the average change in any test being about 2°. Acetone suspensions of the test materials were used to determine their toxicity to fish as compared with DDT at 1 p.p.m., which produced toxic symptoms in 4-6 hours and death in 6-12 hours. The preliminary results indicated that Phosdrin, malathion, para-oxon, parathion, Guthion, and Chlorthion were more toxic than DDT. Materials showing slight toxicity included DDVP, dicapthion, Dipterex, and ronnel (Dow ET-57).

There has been a surge in the development and use of organic-phosphorus insecticides, as indicated by the materials now in commercial or semicommercial use (Metcalf 1959). Though they are highly toxic and great concern has been expressed regarding their use, experience has shown that they can be formulated and used safely in the small amounts required for control of many insects. In aquaria tests some have proved far less toxic to fish than several of the chlorinated hydrocarbon insecticides. Little is known regarding the effects of many of these materials on fish and bottom organisms in nature. The general-purpose residual insecticides and acaricides in this group include parathion, methyl parathion, Diazinon, Guthion, Trithion, Phenkapton, EPN, malathion, Potasan, dicapthion, Chlorthion, sulfotepp, Dipterex, Delnav, Phostex, and ethion; the contact insecticides include TEPP, DDVP, and Dibrom; the plant systemic insecticides embrace dimefox, Phosdrin, schradan, demeton, Meta-Systox, Di-Syston, Thimet, dimethoate, and phosphamidon; and the animal systemics include Co-Ral and Toblene (Dow ET-57) (Metcalf 1959). In addition, many new organic-phosphorus compounds--including Bayer 22408, Bayer 25141, Bayer 29493, Monsanto 7769, and American Cyanamid 12009--are potentially good insect control materials that should be evaluated as to effects on aquatic life.

EFFECTS OF CARBAMATE INSECTICIDES ON AQUATIC LIFE

In other laboratory tests by Bodenstein (unpublished), Isolan appeared to be moderately toxic to Mummichog killifish, causing loss of equilibrium within 1-2 hours at 1 p.p.m. and death within 15 minutes at 5 p.p.m.; no deaths occurred at the lower concentration. Sevin at 5 p.p.m. caused loss of equilibrium within 5 hours, but the fish recovered within 10 hours. Dimetan and Pyrolan at 5 p.p.m. did not kill any

fish over a 24-hour period. It appears from these data that the carbamates are moderate to low in toxicity to fish.

Sevin is a new material which in preliminary studies appeared to be effective against grasshoppers, mosquitoes, and certain insects affecting cotton, fruit, vegetables, and forests. High levels of Sevin fed to cattle for sustained periods did not result in secretion in the milk. This insecticide is effective against the gypsy moth and may fill an important place in control programs where DDT cannot be applied without the hazard of contaminating adjacent pastures because of drift. The apparent low toxicity of Sevin to fish suggest its possible use in areas that include important fishing streams. However, research should be undertaken in the field to evaluate its effects on fish-food organisms and fish. In April 1959 a preliminary study was started near Raleigh, N. C., by workers of Cornell University in cooperation with the Plant Pest Control Division to obtain information on its effects on aquatic life, fish, and honey bees. Another field study involving the spraying of about 75,000 acres of woodland infested with the gypsy moth is being planned for May 1959 by the U. S. Department of Agriculture and the New York Department of Agriculture and Markets, assisted by the New York State Conservation Department and College of Agriculture.

EFFECTS OF OTHER INSECTICIDES ON AQUATIC LIFE

Other types of insecticides coming into use and about which little is known regarding their effects on fish and fish-food organisms include barthrin, Tedion, and Thiodan.

OVERALL EFFECTS OF INSECTICIDES ON AQUATIC LIFE

Since insecticides are poisonous and therefore potentially hazardous to aquatic life, every effort should be made to avoid the contamination of ponds, lakes, and streams. These harmful effects, as indicated by observations recorded in the literature, are minor in view of the vast quantities used annually. Most of the large-scale control operations are under the supervision of competent Federal and State authorities who have carefully weighed the economic benefits of controlling or eradicating serious insect pests against other values. Several of the fish kills reported recently have resulted

from carelessness in application. Steps should be taken to prevent such situations, but occasional minor and temporary losses are to be expected in large-scale operations. Persons opposed to spraying because of damage to fish have failed to produce convincing evidence to substantiate broad claims of fish losses. It is the duty of all concerned with large insect-control operations not only to know what is taking place in the field at the time of treatment and afterwards but also to report fish losses, if any, to the newspapers and later in scientific journals. However, to maintain the proper perspective, it would be only fair to point out the millions of acres in this country have been successfully treated to control or annihilate dangerous insect pests each year without substantial damage to other interests.

PUBLIC RELATIONS AND THE USE OF INSECTICIDES

Since many insecticides are required to control insects that destroy crops, livestock, and man, a great responsibility rests on those developing new materials and recommending them for use. The public needs to be better informed on the many legal requirements that must be met before a new material can be registered by the U. S. Department of Agriculture for use to control pests and to permit interstate shipments. How many people know about Public Law 518, an amendment to the Food, Drug, and Cosmetic Act which prescribes procedures for the establishment of tolerances or exemptions from tolerances for pesticides to assure the consumer of food free from harmful residues?

There also seems to be a real need to advise the public on large control programs well in advance, so that they will understand the aims, nature of operations, benefits, and hazards. There should be close cooperation and trust between officials of different agencies so that all interests will be adequately protected, with special consideration where there are areas of conflict. There are numerous examples in years past of apparent conflicts in connection with control programs, which, after a full exchange of views or cooperative studies resulted in programs that were mutually advantageous and of great benefit to the public.

Seldom are objectors to the use of insecticides farmers or producers who require these materials in making a livelihood. They may

well be hundreds of miles from the scene of operations and lack data to substantiate their claims. Too often unexplained fish kills, small or inconsequential in relation to the total population in the lake or stream, make the headlines, and if there is no readily explained cause, they will be attributed to the use of insecticides if there was any spraying near the area. It is the release of nonfactual information that is giving insecticides a bad name. Even spokesmen for wildlife organizations appear to be ill advised on current control programs and also on findings from toxicological studies of DDT in relation to human health and to fish and wildlife. The use of such information by individuals and organizations is not likely to cement relations between those responsible for insect-control programs and wildlife groups. Of course there is always resort to the courts, such as the DDT-gypsy moth trial last year. This was a time-consuming and expensive trial of doubtful value. The direct and indirect costs would have supported some substantial field investigations to determine the effects of insecticides on aquatic life.

As scientists we have not been telling the public enough about our research. Important discoveries are made each year, and they are in due time recorded in scientific journals. However, they also should be brought to the attention of the public through popular media. Perhaps a better appreciation of our research programs, and their application to practical control problems--such as the eradication of the Mediterranean fruit fly from Florida, the apparent eradication of the screw-worm from the Southeast, the efficient control of mosquitoes in many parts of the country, the economic control of devastating forest insects, and the control of hundreds of injurious insects on crops--would lead to better support for research, particularly in areas where there are joint interests, including effects of insecticides on aquatic life. Some of these programs might be of great value in wildlife conservation. The elimination of the screw-worm from the Southeast, for example, will certainly result in an increase in deer and other game.

PRESENT AND FUTURE RESEARCH

The Entomology Research Division recognizes the benefits and limitations of many control methods and is striving to solve the most urgent problems with available resources. In recognition of the importance of reducing hazards,

emphasis is being placed on safer chemicals and on methods of using them with maximum safety. Research on biological agents is being stressed where this type of control appears useful, either alone or in combination with insecticides. Additional crop varieties resistant to insect attack need to be developed. Basic studies are being initiated on the possible use of selective chemicals, such as, hormones and growth inhibiting substances. New ways will be sought to use insecticides, as in baits with attractants, in order to lessen the amount of toxicant required. Advancements are being made in the development of systemic materials that are specific against certain pests, and of new formulations and materials that are effective against pests but less toxic to other animals. A unique new approach in insect control involves the continued release of males sterilized by gamma rays from a cobalt-60 source to destroy the reproductive potential of natural populations of the screw-worm fly. This technique, which leaves no residues or other undesirable effects, may be useful in the control of other insects, but extensive research will be required to make such determinations.

With the expanding use of insecticides there is a marked need for broad cooperative studies between entomologists, fishery biologists, and chemists to determine the direct and long-term effects on aquatic life of insecticides in current use and those expected to be used in future control programs. It is evident from a review of recent literature that there have been no detailed studies on effects of insecticides on fish-food organisms except for DDT. There have been some excellent laboratory studies evaluating the comparative toxicity of new materials to fish but the real test comes in evaluating them under field conditions when many variables are operative, such as (1) ecological differences in ponds, lakes, and streams, (2) a great variety and abundance of aquatic insects with different habits, (3) variation in fish populations and their susceptibility to poisoning, (4) variation in shore line or tree canopy, (5) proximity to untreated water to furnish immigrants for repopulation, and (6) influences of weather on the application and distribution of the insecticide. In field experiments there must be suitable controls and pretreatment samples. Certain chemical control treatments may greatly reduce aquatic organisms. However, natural phenomena, such as flash floods, can cause catastrophic losses of bottom organisms. There is need for basic

studies to determine the relationship between the abundance of bottom organisms and fish populations. Past studies indicate that fish have food preferences and also that they are opportunists. Thus, a considerable but temporary loss of bottom organisms may be of little importance. Following spraying, fish will feed on terrestrial insects falling on the water and on those bottom organisms available, which might not be normally utilized but which survived the spray. On the other hand, certain treatments might cause heavy losses of aquatic fish foods which would be replaced very slowly and thus affect the condition of the fish.

Studies are needed to determine more exactly what happens when a lake or stream receives an insecticide spray. How much insecticide reaches the water and how long can it be detected in water samples? Does it settle out into the mud or on bottom vegetation or is it blown to the shore in an oil film? If absorbed on mud or vegetation, is it available to poison small animal life or fishes? Are fishes killed from direct contact with the spray or from feeding on spray-killed insects, or both? Why do some fishes gorge on treated insects in sprayed areas and survive whereas others die? Are these effects merely transient, or can important fish losses occur long after spraying because of insecticide accumulation in the stream? I am convinced that water turbidity and high organic content can nullify the effect of DDT on fish. A careful study of this matter might lead to ways of introducing a material into a stream or artificially muddy-

ing the water for a brief time during the spray operation to curtail the toxic effects of the insecticide on fish.

The literature covers instances in which fish losses occurred following run-off of insecticides from treated fields, especially cotton, into creeks and rivers. Unfortunately these rivers were not sampled for bottom organisms and fish before spraying or, in some cases, very satisfactorily after spraying. A study is needed to evaluate this situation, bearing in mind the extensive use of cotton insecticides, the different degrees of breakdown of insecticides in different soil types, rainfall intensity and land cover, and absorption of the insecticide by the soil. As yet no one has shown insecticide run-off from forests into streams in sufficient amounts to show a measurable increase in the mortality of bottom organisms above that caused directly by the spraying.

Research is needed to develop better formulations and equipment for dispersing sprays to minimize losses of toxicant, from the air, and removal by rain from the target plant. The improvement of operational procedures, especially for aerial spraying, might well reduce the hazard of insecticides to aquatic life. There is a definite need for a manual to cover the many problems that arise in connection with any large scale aerial spray program. A manual based on the best procedures developed through the years of experience would serve as a helpful guide for the conduct of effective and safe programs.

REFERENCES

- Bruchhausen, Walter. 1958. United States District Court, Eastern District of New York. Robert Cushman Murphy, et al., Plaintiffs, against Ezra Taft Benson, Secretary, USDA, et al., Defendants. Civil No. 17610. June 23. 20 pp.
- Cope, O. B., and P. F. Springer. 1958. Mass control of insects: the effects on fish and wildlife. *Bul. Ent. Soc. Amer.* 4(2):52-56.
- Entomology, Research Division. 1959. Insecticide recommendations of the Entomology Research Division for the control of insects attacking crops and livestock - 1959 Season. ARS and FES, Agriculture Handbook No. 120. 129 pp.
- George, J. L., R. F. Darsie, Jr., and P. F. Springer. 1957. Effects on wildlife of aerial applications of strobane, DDT, and BHC to tidal marshes in Delaware. *Jour. Wildlife Management* 21(1):42-53.
- Graham, R. J., and D. O. Scott. 1958. Effects of forest insect spraying on trout and aquatic insects in some Montana streams. Final Rept. 32 pp., 19 tables.
- Harrington, R. W., Jr., and W. L. Bidlingmayer. 1958. Effects of dieldrin on fishes and invertebrates of a salt marsh. *Jour. Wildlife Management* 22:76-82.
- Henderson, C., and Q. H. Pickering. 1958. Toxicity of organic phosphorus insecticides to fish. *Trans. Amer. Fish. Soc.* 87:39-51.
- Hoffman, R. A. 1957. Toxicity of three phosphorus insecticides to cold water game fish. *Mosquito News* 17(3):213.
- Hoffmann, C. H. 1958. The truth about chemical controls. *Amer. Forests* 64(11):12-13, 35-38.
- Hoffmann, C. H., and A. T. Drooz. 1953. Effects of a C-47 airplane application of DDT on fish-food organisms in two Pennsylvania watersheds. *Amer. Midland Nat.* 50(1):172-188.
- Knipling, E. F. 1953. The greater hazard -- insects or insecticides. *Jour. Econ. Ent.* 46(1):1-7.
- Lay, D. 1958. Count three for trouble. *Tex. Game and Fish* 16(7):4-7.

Lieux, D. B., and J. A. Mulrennan. 1955. Mayfly control. *Mosquito News* 15(3):156.

Metcalf, R. L. 1959. The impact of the development of organophosphorus insecticides upon basic and applied science. *Bul. Ent. Soc. Amer.* 5(1):3-15.

Parker, D. E. 1956. The effects of DDT on wildlife. *Idaho Wildlife Review* 8(6):5-7.

Rudd, R. L. 1958. The indirect effects of chemicals in nature. Paper given at the 54th Annual Convention of the National Audubon Soc., Nov. 10. 5 pp.

Rudd, R. L., and R. E. Genelly. 1956. Pesticides: Their

use and toxicity in relation to wildlife. State of Calif. Dept. of Fish and Game Bul. No. 7. 209 pp.

Shepard, H. H. 1958. The pesticide situation for 1957-58. Commodity Stabilization Serv., Food and Materials Requirements Div., USDA. 23 pp.

Tarzwel, C. M. 1958. The toxicity of some organic insecticides to fishes. Presented at the 12th Ann. Conf. Southeastern Assoc. Game and Fish Commissioners, Louisville, Ky., Oct. 19-22. Printed by Southeastern Assoc. Game and Fish Commissioners, Columbia, S. C.

Tarzwel, C. M., and C. Henderson. 1957. Toxicity of dieldrin to fish. *Trans. Amer. Fisheries Soc.* 86:245-257.

EFFECTS OF FOREST INSECT SPRAYING ON TROUT AND AQUATIC INSECTS IN SOME MONTANA STREAMS

Richard J. Graham - Fish & Game Department, Bozeman, Montana

ABSTRACT

The paper is a summary of findings from a cooperative study made by the U. S. Forest Service and Montana Fish and Game Department. Observations on bottom organisms and fish populations were made on seven streams sprayed with DDT in 1956. (Project F-21-R-1, Job I). By the end of the summer volumes on one of the streams exceeded prespray volumes. On five streams, quantitative recovery had progressed considerably but did not equal prespray volumes,

while on the seventh stream recovery was practically absent. Game fish reductions of 70 percent and 80 percent occurred on two of the seven streams. Observations were made on four rivers and one lake in conjunction with the 1957 spray program. Fish mortalities were observed on two of the rivers and the lake. The attitude of the Montana Fish and Game Department regarding the forest spraying is presented.

The Montana Fish and Game Department did not become directly concerned with the aerial spraying of insecticides until adverse effects to fish were associated with the spruce budworm control program. This fish mortality on the Yellowstone River was reported at the 1956 Seminar on Biological Problems in Water Pollution by Mr. O. Lloyd Meehan of the U.S. Fish and Wildlife Service.

Spruce budworm epidemics in Montana were reported as early as 1923, but most of these outbreaks were of short duration and subsided from natural causes. The current infestation, first reported in Montana in 1948, continued to spread so that by 1951, the U.S. Forest Service decided to attempt chemical control with DDT. During 1952 and 1953, "hot-spot" spray programs were conducted on several forests in Montana and in Yellowstone National Park. These were followed by more extensive programs amounting to the treatment of approximately 300,000 acres in 1955, 900,000 in 1956 and 800,000 in 1957.

During October 1955, four months after spraying in the area, the Montana Fish and Game Department received reports of dead and dying fish in the Yellowstone River. Mortalities were observed on about 90 miles of the river within and below the spray area. Dead fish were primarily whitefish (Prosopium williamsoni), brown trout (Salmo trutta) and suckers (Catostomus

spp.), and densities of about 600 fish in less than 300 yards of stream were noted. Bottom organisms were sampled in treated and untreated areas and comparison showed a noticeable absence of aquatic insects in sprayed areas. Attempts to collect adipose tissue from dying fish failed because of their emaciated condition. DDT was found in brain, liver and kidney tissues on a sample of moribund whitefish.

In attempting to explain this unusual mortality, fishery biologists looked to the spruce budworm control program carried out in July as it was the only apparent activity in the area that was different from other years.

The Forest Service had made inquiries into possible danger to fish and wildlife from DDT and had been informed that when used at less than two pounds per acre, there would be little or no adverse effects. A review of the literature, however, disclosed conflicting observations. Fish mortalities attributed to DDT were reported in at least 11 states (including Alaska) and also Canada. Most important of these were in Oregon where losses were reported on steelhead fingerlings and on the Miramichi River in New Brunswick, where severe losses of young salmon occurred. Although DDT had been studied more than any other insecticide, much of the information available was fragmentary and not relevant to the situation in Montana. As a result, a cooperative study was initiated in

1956, in conjunction with the current spray operations. The immediate objective was to determine if the aerial application of one pound of DDT per acre resulted in any fish mortalities and ways of minimizing any possible detrimental effects.

Agencies cooperating in the study included the U. S. Forest Service, the U. S. Fish and Wildlife Service, Montana State College, and the Montana Fish and Game Department. This discussion is merely a summary of the more important findings and conclusions. More detailed information may be obtained from Dingell-Johnson completion reports of the Montana Fish and Game Department and Forest Service bulletins.

The general design of these studies was to sample stream bottom organisms and fish populations prior to and following spraying. Bottom organisms in small streams were sampled with a standard square-foot sampler but in larger streams, a square-yard sampler was used. Five-square foot or two-square yard samples were taken at each established station. The number of bottom sampling stations per stream varied from two to eight. The insects were sorted to order and volumes were measured by displacement.

Fish populations were sampled with an electrical shocking device. Sampling was done in sections 300 feet long and the number of sections per stream approximately duplicated the number of bottom sampling stations. Only fish at least three inches long were used in population index numbers since smaller fish could not be efficiently collected.

The spray used in this operation consisted of one pound of DDT dissolved in 1.25 quarts of hydrocarbon solvent and diluted in sufficient fuel oil to make one gallon of insecticide. Oil-sensitive dye cards were placed along stream banks to determine the amount of spray reaching stream study sections.

Thirteen trout streams were selected for study during 1956. Six of these streams were later dropped because the expected amount of spray did not reach the stream or the data collected were insufficient for significant results.

The studies on these streams showed that aquatic bottom organisms were substantially

reduced by the spray. The volume of drifting insects on two streams which were intensively studied increased 100 times from before spraying to one hour after spraying. Based on bottom samples, reductions of over 90 percent of the volume within a week after spraying, were common. Sampling on two streams continued throughout the summer and fall. By October, insect recovery in these streams represented only a small fraction of the normal volume as indicated by control stations. Downstream effects on the waters varied but, in general, decreased within a few miles below the spray area.

A total of 158 trout were held in live cages in two streams during spraying. None of these died on spray day or during the three days following. Comparison of fish populations before and after spraying was difficult since high water prevented efficient prespray sampling. The census did not reveal any fish losses within a month after spraying.

The seven streams were studied again during 1957 to observe any delayed effects on fish and the recovery rate of bottom organisms.

The sampling indicated that by the end of the second summer the volume of bottom organisms on one of the streams had reached prespray quantities. On five streams, quantitative recovery had progressed considerably but did not equal prespray volumes. Whether or not the recoveries were qualitative as well as quantitative could not be determined by the methods used. On the seventh stream (one of the most productive of bottom fauna) only a trace of aquatic organisms in sprayed sections was found during the second summer.

Fish populations in the second summer on five of the streams approximated those of the previous year. Some slight declines in numbers were noted but these could have been the result of normal population fluctuations.

On the sixth stream (Musselshell River) the number of brook trout in the two study sections in July 1956 was 253. In August 1957, only 75 were recovered. This decline (about 70 percent) is more than would be expected in normal population fluctuations. Although the number of trout three inches and larger decreased, numerous live one- and two-inch fish were observed.

Five study sections had been established on

the seventh stream (Sheep Creek). The upper three sections were in the spray area and the lower two were several miles below. The number of game fish sampled in the lower two sections remained about the same between 1956 and 1957 while numbers in the sprayed sections decreased from 180 to 29 or about 84 percent. Many sculpins (*Cottus* sp.) were observed in these sections in 1956 but none were seen in 1957. This is also the stream where aquatic insect recovery was practically absent. These two streams were sampled again in 1958. The numbers of fish in the affected sections had increased to approximately those of 1956, however, these were predominately young fish. Again, no sculpins were found in the sprayed sections of Sheep Creek. Analysis of bottom samples is not complete but insect recovery appears to have progressed considerably.

In 1957 it was decided to intensify investigations on a single stream. Principle effort in this study was directed toward (1) the chemical analysis of water, vegetation, sediment, and fish tissues to determine the presence of DDT and (2) patrolling the stream to observe fish mortality.

Approximately three miles of the Ruby River were sprayed at the rate of one pound of DDT per acre. Immediately after spraying the surface water contained 1.35 p.p.m. DDT while sub-surface water contained less than 0.1 p.p.m. The quantities detected decreased rapidly and within 32 hours, only a trace could be found.

The effect of this spray on bottom organisms was similar to that observed in previous studies.

High water again prevented efficient sampling of the fish population but it was determined that suckers were by far the most abundant fish. Dead suckers began to appear within a few days after spraying. In a regularly patrolled section (about three miles long) the number found per day increased to 80 about 10 days following spraying. Dead suckers were found throughout the summer and fall but in smaller numbers. The mortality extended downstream for about eight miles below the spray area.

No dead trout were found during the summer. However, in more suitable trout habitat, about five miles below the spray area, dead brown trout and whitefish were recovered in November and December. The extent of the die-off could

not be determined because of sampling and patrolling difficulties but it was certainly greater than usual, even during the spawning season.

Whole fish, ground and blended, were chemically analyzed for DDT and it was found in all fish (dead or alive) collected after the spraying. The amounts found, varied from less than one p.p.m. to about six p.p.m., but in some cases, more DDT was found in live fish than dead fish. Later experimentation showed that the variations resulted from chemical procedures as well as sampling methods. If this type of information is to be used in future studies, more refined methods have to be developed. In any case, the amount of DDT that might cause death would vary with environmental factors and condition of the fish.

No DDT was found in bottom sediments collected before or after spraying. DDT was found on aquatic vegetation samples collected as late as September and for at least 10 miles below the spray area.

Mortalities following spraying were observed in two other areas during 1957. About 50 dead trout were found along the shoreline of a small mountain lake a few days after spraying. An oil film on the water surface was reported on spray day and DDT was found in the dead fish. On the Big Hole River, suckers began to die a few days after spraying. The die-off lasted about three weeks and extended for at least five miles below the spray boundary. During that winter a whitefish die-off occurred in the same area but only a few dead trout were observed. No regular observations were made in these areas and the extent of the damage was not determined.

Other important observations were made during the course of the study. The limited data collected on young fish in streams did not show that they were more susceptible to DDT than older fish. However, during 1957 the Montana Fish and Game Department undertook laboratory bio-assays, under controlled conditions, on the effects of DDT on trout and whitefish. These continuous-flow, bio-assays showed that high mortalities occurred with trout less than 1.5 inches long at concentrations as low as 0.02 p.p.m. Three to five inch fingerlings proved to be the most tolerant while larger fish again exhibited high mortalities.

The effect of various physical, chemical and

biological factors on mortalities in streams could not be determined since the concentration of DDT in the water and length of exposure were not accurately determined. Bio-assays showed that slight environmental changes, such as a three degree increase in water temperature, resulted in an immediate increase in mortality rates.

Observations also showed that delayed mortalities occur and these are generally more serious than those occurring immediately following spraying. Game fish comprising the bulk of observed mortalities were brown trout, brook trout (*Salvelinus fontinalis*) and whitefish. All of these are fall spawners. On the two rivers where heavy sucker mortalities were observed in 1957, indications were that the suckers were in the process of or had completed spawning just prior to spraying. It is possible that poorer condition and physiological stress due to spawning may result in stored DDT becoming lethal. Bio-assays conducted during 1957, substantiate this view.

The study also shows that fish die-offs due to the spraying may occur and not be reported by sportsmen or local residents. This is particularly true when the mortalities occur in the fall, after the fishing season. If it were not for the studies, fish mortalities would not have been

observed on three of the five streams where they occurred. Although over two million acres of Montana's forests have been sprayed, the Fish and Game Department considers much of the program to be experimental. The necessity of the attempted controls in many areas is certainly questionable. There is also considerable doubt as to the effectiveness of the control program. This doubt is expressed by many plant and animal ecologists, zoologists, and entomologists. Control of the budworm on large areas of the 1953 to 1955 programs was unsuccessful and many of these areas were scheduled for re-spraying in 1959.

Considering these various aspects, the Montana Fish and Game Department is not willing to compromise the sport fishery resource for programs of questionable necessity and doubtful success. Department biologists are definitely opposed to spraying where valuable fish resources are endangered.

The department will continue to cooperate with the Forest Service in determining ways to minimize adverse effects. We feel that investigations on side effects have lagged far behind research on chemicals to kill pests. The department strongly advocates more research on the need for the various chemical controls, the effectiveness of the so called controls and the effects upon other resources and public health.

AERIAL FOREST SPRAYING IN CANADA IN RELATION TO EFFECTS ON AQUATIC LIFE

F. E. Webb, Canada Department of Agriculture, Division of Forest Biology
Fredericton, N. E.

ABSTRACT

Nowhere else in the world has the development of large-scale aerial chemical control against forest insects been a more logical development than in Canada. In the few years since the method became economically and operationally feasible, it has taken its place as an adjunct to the management of large, relatively inaccessible forests where other methods are yet ineffective. Further improvements in technique undoubtedly are possible and research on insecticides may be expected to uncover new compounds and formulations that will be more effective, or more selective in their action than DDT. It seems safe to say that the method will continue to be used with improved efficiency against an increasing number of pests.

No large-scale forest spraying project should be undertaken without a full realization of its possible adverse consequences. However, it is not sufficient to oppose the method on the basis of some vague notion of "disturbing the balance of nature". A more precise knowledge must be gained of the effect of introducing the new and powerful control factor into an already complex biological system. The full potentialities of the method can only be determined from tests on a sufficient scale to achieve their purpose, and operations such as those of recent years in Canada provide the neces-

sary opportunities. The biologist's task is to foster the idea that the problems of pest control are primarily ecological and, by means of properly integrated studies of the whole ecosystem, to ensure the safest and most intelligent use of direct control measures.

The exceptional value of salmon fisheries affected by recent spraying in Eastern and Western Canada has helped to focus attention on this problem in Canada. It is feared that drastic reductions of the immature freshwater stages by DDT poisoning will be reflected in reduced runs of adults when those generations return from the sea. The maximum effect in New Brunswick is predicted for 1961. Fortunately, adequate and prompt restocking of the affected streams has been assured by exceptionally good runs of adults into affected streams in 1958, in line with improved catches of the species throughout the Atlantic range.

Research is continuing to measure ultimate effects on fish and food fauna and on the possibility of using less damaging insecticides, dosages and formulations. No alternative has yet been found to match DDT as the most efficient insecticide against forest insects from the entomological and economic viewpoints.

EARLY CONCERN ABOUT ADVERSE EFFECTS

The possibility of adverse effects of DDT on the general forest fauna has been a matter of concern to forest entomologists in Canada since this insecticide first became available in commercial quantities. This is evident from the fact that the first instances of its wide-scale use, against spruce budworm in 1945 and 1946 in the Lake Nipigon area of Ontario, were preceded, and based in part, on field and laboratory tests of its toxicity to other forms of life sponsored by the Ontario Dept. of Lands and Forests in Algonquin Park in 1944. A Department Bulletin on these tests and on the operations of the next two years contains reports on the effects against fish and invertebrate aquatic life, amphibians and reptiles, and birds and small mam-

mals. These were somewhat limited tests but they showed what has since been corroborated a number of times, that field applications of DDT are toxic to most other forms of animal life, particularly aquatic and amphibious life. They also suggested, however, that severe or lasting damage would be unlikely from the low dosages that appeared to be sufficient for a high percentage kill of the pest population. Certainly, it was felt, this damage would be unlikely to match the disruptive effect on the forest community of allowing widespread severe spruce budworm damage to go unchecked. Since that time, of course, a good deal more has been learned of the potentialities and dangers of this and other insecticides, and the study of the problem has increased rapidly in importance as a specialized branch of agricultural and forest biology.

IMPORTANCE OF FOREST INSECT CONTROL IN CANADA

In introducing this subject with respect to the Canadian situation I believe it is important to point out some of the special problems and needs in forest insect control and to explain something of the philosophy and procedures adopted thus far in the use of large-scale chemical control methods.

Canada is above all a forest country. Forests occupy far more than half the land area of the ten provinces and extend across the country in a continuous band 600 to 1300 miles wide. Forest industries, notably Pulp and Paper, lead all other Canadian industries as a source of foreign exchange - a fact of considerable significance in an economy in which unfavorable total trade balances are a chronic check on the national prosperity.

Canada's most extensive forest types, typified particularly by the Boreal forest, are characterized by huge areas of more or less uniform stands, commonly even-aged and dominated by one or two of the conifers. In these relatively unstable ecological associations, insect outbreaks have in the normal course of events, played a dynamic, but often cataclysmic role, along with disease, fire and blowdown, in the periodic replacement of successive forest crops. To a degree Canadians have always had to compete with these destructive natural agencies but it has been particularly with the rapid development of the Pulp and Paper industry with its full use of the forest growth that they have become serious economic problems.

ALTERNATIVES IN FOREST INSECT CONTROL

Canadian forest entomologists have long supported the philosophy that the ideal in insect control is prevention rather than cure. No doubt until the advent of DDT and the aerial method this opinion was shaped by the sheer impracticality of applying chemical control measures from the ground against outbreaks of an insect such as the spruce budworm, often involving hundreds or thousands of square miles of inaccessible forest. From the earliest years keen and active interest has been shown in Canada in the possibilities of biological control involving the propagation and dissemination of natural enemies of pests - parasites, predators

and disease microorganisms. So far, however, this approach has been successful chiefly against introduced pests that apparently arrived on this continent without a full complement of natural enemies. The greatest promise for ultimately reducing the threat of the most serious native forest insects is undoubtedly the creation of more resistant forests by silvicultural means. In the case of the spruce budworm, for example, it is believed that the threat of recurring outbreaks can be minimized through planned exploitation of the most susceptible stands as they mature and by breaking up the age structure and favoring less susceptible species in the next crop. The implementation of such a program, however, takes time, and in the meantime it is necessary to adopt more direct measures to preserve existing supplies of raw materials and to prevent the disruption of management plans already underway and aiming at sustained yield and more resistant future crops.

RECENT OPERATIONS AND SPRAYING POLICY

By far the most serious forest insect problem in Canada, and one to which the aerial spraying method is especially well suited, is that involving the spruce budworm. This insect is a pest in each of the ten provinces but it is chiefly notable for periodic spectacular outbreaks and damage in the spruce-fir forests extending from western Ontario through Quebec to New Brunswick on the Atlantic coast. Of over nine million pounds of DDT used on aerial forest operation since 1945, more than 98 percent has been used against this insect alone.

Canadian forest spraying operations to date have been initiated, organized and executed by the owners and operators of timberlands. The Division of Forest Biology has no regulatory authority but is responsible for technical advice and assistance and for assessing results. To date the Division has adopted the most conservative policy possible in recommending spraying. Treatment of an outbreak has been delayed until tree killing would be certain without it. This has meant that spraying in any one year has involved only a fraction of the total area of severe attack of a particular outbreak. This policy is in contrast to programs of eradication such as those carried out in the U. S. against gypsy moth. It involves a greater risk of failure than more liberal or earlier dosages but it has advantages in cost and is believed to be less

likely to have adverse effects on the course of the outbreak or on other forms of life. Less damage is also to be expected in Canadian spruce budworm operations since 1953 from the lowered dosage of 1/2 pound DDT per acre, which is half that used against this insect elsewhere and customarily recommended against forest defoliators in general.

DAMAGE TO FISHERIES BY RECENT OPERATIONS

It has been a somewhat fateful coincidence that recent forest spraying in Canada has been carried out at extreme opposite ends of the country, on the Atlantic and Pacific seaboard. Record-sized spruce budworm operations of some 18 million acres, more than 2/3 of all the acreage sprayed against this insect in the U.S. and Canada since 1945, were completed between 1952 and 1958 in New Brunswick and adjacent areas of Quebec. The area included watersheds of some of the finest Atlantic salmon streams in the world. In the West a relatively small operation of about 150,000 acres against black-headed budworm on Vancouver Island in 1957 affected a number of important spawning streams of western salmon species. No doubt it has been largely owing to the special value of these particular fish species, both as commercial and game fish, that particular attention has been focussed on the adverse effects that have followed these spraying operations and that rather intensive investigations have been undertaken to study them.

Studies of effects on fish are a responsibility of the Department of Fisheries and the Fisheries Research Board of Canada and I shall not presume to review their results in detail. Suffice it to say at the moment that drastic reductions have occurred in the smallest age classes of salmon in some sprayed streams in both N. B. and B. C. and that it is feared that this will be reflected in serious reductions in the number of adults of these generations returning from the sea. Fortunately, the outbreaks in both the East and the West have now subsided and little or no spraying should be required there within the next few years. The maximum effects on returning salmon runs in New Brunswick are expected by 1961. It is encouraging to note at the moment that exceptionally good runs of salmon were reported in 1958 in streams affected by the spraying in the earliest years, in line with improved catches that were general for the

species throughout its range in the Atlantic. This is particularly good news because of the assurance it gives of prompt and adequate restocking of the species in the affected streams.

EFFECTS ON FISH-FOOD FAUNA

Federal Fisheries groups are also primarily responsible for studies of effects on fish-food organisms. In New Brunswick this work has been carried out chiefly by F. P. Ide on a branch of the Miramichi River system, first sprayed in 1954. Results of these studies for the first two years were reported some months ago in the Transactions of the American Fisheries Society. Yard-square cages have been used since 1955 to measure the numbers and volumes of adult insects emerging from selected sprayed and unsprayed streams in the course of successive seasons. Some salient features of his results, as published in the aforementioned paper and in subsequent unpublished reports, are as follows:

(1) The immediate effect of spraying is a drastic reduction in the emergence of all insect forms for several weeks.

(2) Chironomids show the first signs of recovery, often in the same season. Populations of these minute insects by late summer are often phenomenally large, but in bulk, represent only minor fish-food volumes.

(3) One to two years after spraying total numbers of emerging insects tended to exceed prespray numbers but volumes were reduced by 1/2 to 2/3 owing to the predominance of minute forms. After chironomids, signs of recovery were first evident in the case of small mayflies and stoneflies.

(4) Of the larger insects, caddisflies showed particularly severe reductions and appeared to be virtually eliminated in the immediate postspray years. A degree of recovery was evident in 1958, however, in streams sprayed two to four years previously.

An aspect of these combined insect-fish studies that may be of particular interest to students of population dynamics is the evident ability of these natural populations to compensate for adversity. There is evidence in some of the most recent results to suggest that the prompt recovery of abnormally large populations of minute insects and relative lack of

competition favors exceptionally rapid growth and survival of the immediate postspray salmon spawning. As a result, precocious individuals of this generation may subsequently go to sea and return as adults a year earlier than normally, thus tending to smooth gaps in the adult population structure that were expected to result from the spraying.

In addition to Ide's work on the Miramichi a limited assessment of effects on aquatic fauna has been undertaken by staff of this Division on the Upsalquitch and Charlo watersheds. This work was started in 1955 to supplement the Miramichi results with data from streams of longer and more varied spraying history. Pre- and postspray samples of the standing bottom crop have been taken each year, using the Surber "square-foot" device, in five sprayed streams and one unsprayed check stream.

In the initial stages, at least, this work showed general agreement with similar studies such as those by Hoffman and Drooz in Pennsylvania and Cope and Park in Montana. It is unique, however, with respect to the relatively long and continuous spraying history of the streams; each has been sprayed at least four times, and one stream has been affected by nearby experimental spraying each year from 1952 to 1958. Because of the difference in sampling technique the data provide an interesting comparison with Ide's results and also give some idea of relative effects on non-insect fauna. However, it must be emphasized that the estimates are gross, because of the limited sampling and because identification in most cases were not taken beyond order of phylum.

The following is a summary of results:

(1) Severe immediate reductions of all insects invariably occurred immediately following spraying.

(2) In numbers, caddisflies appeared to be the most severely reduced insect group, followed in order by stoneflies, Diptera (including midges, blackflies, etc.), Dobson flies and mayflies.

(3) Mayflies have shown the greatest tendency toward rapid repopulation. Recovery was also evident for Chironomids and blackfly species, but the former were not collected in numbers equivalent to those found in cage traps

by Ide. According to Ide this may be owing to the inefficiency of the Surber device in collecting extremely minute immature forms.

(4) Non-insect fauna, principally various types of worms, snails and water mites, appear to be relatively immune to poisoning and have shown little or no reduction. Indeed, Oligochaetes and snails have been found in considerably larger numbers and volumes in the stream sprayed every year, than in any other stream including the check.

(5) As might be expected, insects have been extremely scarce in the stream sprayed every year. An exception occurred in the last year, however, when late-season sampling showed 40-fold increase in numbers, mainly small mayflies. This raises the interesting speculation as to whether the development of DDT immunity is a possibility in aquatic insect populations treated in this way.

(6) Extreme impoverishment of both insect and non-insect fauna in one of the streams appears to be the combined result of DDT and the disturbance of the bottom habitat by stream-driving for pulpwood.

(7) The several years' data indicate a tendency for individual streams to exhibit characteristic and consistent differences in faunal composition. This and the inherently high variability of samples taken in this way pose a difficult problem in experimental design and call for extreme caution in analysis.

THE INTERDEPARTMENTAL COMMITTEE AND RESEARCH ON ALTERNATIVE INSECTICIDES

A direct outcome of the reports of severe damage to fish in the operations East and West was the formation in January, 1958, of a Federal Interdepartmental Committee on Forest Spraying representing the Fisheries Research Board and Dept. of Fisheries, the Federal Forestry Branch and Wildlife Service, and the Division of Forest Biology. The objectives are twofold: to review proposals for forest spraying in Canada from the point of view of all resources concerned, and to assess the need for research in this field. As a first result, studies were undertaken last season in both laboratory and the field to test the relative effectiveness of possible alternative insecticides against insects and

fish. To conclude, I should like to present the following abridgement of a summary of results prepared by J. J. Fettes, Head of the Chemical Control Section of this Division.

Three insecticides were tested against DDT:

DDD: an analogue of DDT

Sevin: a carbamate

Korlan: an organic phosphate

Previous reports on each of these had shown some promise of less severe effects to other forms of life. Tests were carried out at the Nanaimo Biological Station on juvenile coho salmon, which were found to compare in susceptibility to DDT to Atlantic salmon. These showed DDT to be about twice as toxic as DDD, four times as toxic as Korlan, and 18 times as toxic as Sevin.

Aerial field tests in New Brunswick showed that the alternative insecticides were also less toxic to spruce budworm, in the same order as for fish, indicating that the volume of these insecticides required for effective control would be prohibitive. Similar results were obtained by laboratory tests.

Somewhat greater promise was indicated by tests involving lower dosages of DDT. Plots treated with 1/4 lb. DDT in one gallon of oil-solvent showed acceptable spruce budworm control but no observable effects on salmon smolts and only a slight reduction in insect numbers.

Further tests of the feasibility of lower dosages and concentrations of DDT are planned for 1959. Additional tests will also be carried out using Malathion, since previous tests against this insecticide have proved somewhat inconclusive.

EFFECTS ON YOUNG SALMON OF FOREST SPRAYING WITH D.D.T.

C. J. Kerswill, P. F. Elson, M. H. A. Keenleyside and J. B. Sprague
Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B., Canada

The spruce budworm in New Brunswick, and the extent of spraying, have been discussed in another paper in these Proceedings by Dr. F.E. Webb. Basic studies of population dynamics of salmon were in progress before this spraying took place. These studies continued during spray operations, and afterwards.

In one part of the work, numbers of young salmon in the Northwest Miramichi River were estimated yearly at 10 stations by repeated electrofishing combined with marking and recapture of fish. Results up to 1957 are shown in Figure 1. Numbers of young salmon increased from 1950 to 1953, apparently because predatory

birds were controlled.

Spraying in 1954 virtually eliminated salmon fry and killed most parr. Large numbers of fry in 1956 can be credited to reduced competition, good spawning conditions, and no spraying. Numbers of fish were again reduced during 1956 and 1957 in portions of the watershed which were sprayed. There were indications of changes in growth rates in the years following spray operations, and these changes are currently under investigations.

Reprints of this and other portions of the work in more detail may be obtained by writing to the senior author.

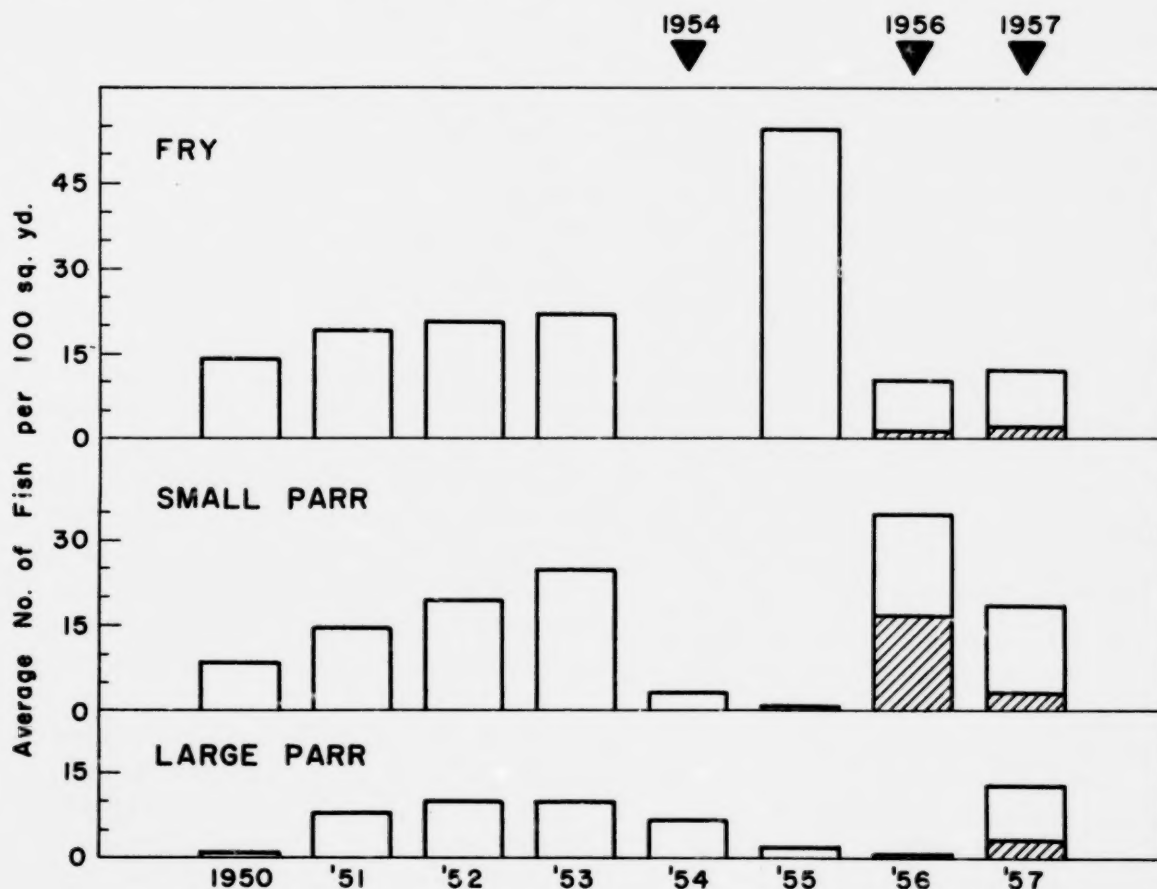


Figure 1. Abundance of three sizes of young salmon in the Northwest Miramichi River. Solid triangles indicate years when DDT was sprayed in the area. Cross-hatching indicates fish found in sprayed part of the watershed. Fish found in any one year are given by bars directly above that year. Previous to 1954, a year class as judged by size can be followed diagonally downwards to the right.

THE RETENTION OF D.D.T. BY TROUT AND WHITEFISH

Oliver B. Cope - U. S. Bureau of Sport Fisheries and Wildlife,
Denver, Colorado

ABSTRACT

DDT is commonly stored in tissues of birds and mammals and in the fatty tissues of most humans in this country. Very little has been recorded about the storage of DDT in fish. The present study describes findings on DDT storage in trout and whitefish bodies after exposure to DDT sprayed over large areas in Montana and Wyoming.

DDT was found in individual trout tissues by chemical analysis; the greatest concentration was in fat. Kidney held the second highest amount, followed by pyloric caecum and brain; liver contained none.

In more extensive studies involving blended whole bodies of fish, whitefish contained more DDT and DDE than did rainbow, cutthroat, and brown trout. All fish collected had DDT in their bodies. Fish taken 85 miles downstream from the spray area were positive for DDT. DDT was found in fish at all seasons, up to the last ones analyzed, 11 months after the spray. DDT was also found in all control fish, some from an untreated stream, some from a hatchery, and some from a fish market. As a check on the analytical test, control fish were bioassayed with fly larvae; the control fish had DDT. This leads to the question of just how widespread is the retention of DDT in fish populations in this country.

The storage of DDT and its metabolites, DDE and DDA, has been the subject of considerable study in insects, mammals, and birds. An understanding of the fate of DDT after entry into the body is essential to a knowledge of the onset of DDT morbidity or mortality in the animal body, so it is logical that studies on DDT should have taken this course as the use of the insecticide became prevalent. The role of storage of DDT appears to be particularly important in the case of chronic effects, especially when the mobility of stored toxicant makes it available to affect other tissues and systems.

It has been said that DDT has been disseminated so widely that an experimenter wishing to work on a DDT-free cow or sheep finds it virtually impossible to locate such an animal. Knowing of the passage of DDT through the placenta, from mother to milk (Telford and Guthrie, 1945), and from hens into eggs (Bryson, *et. al.*, 1949), it is easy to visualize the entry and perpetuation of DDT in animal bodies in the face of the widespread coverage that DDT has enjoyed since World War II. Extensive storage of DDT has been demonstrated in human bodies. Pearce, Mattson, and Hayes (1952) found all samples measured to be positive for DDT and DDE in

human fat from the general population. More recently, (Hayes, *et. al.*, 1958), 342 samples of fat from humans were analyzed for DDT and DDE, and it was found that people with occupational exposure stored more DDT-derived material than other people, and that people on meatless diets stored about half the concentration found in people in the general population.

These facts lead to questions concerning the storage of DDT and DDE in fish. It has been assumed that fishery biologists do not have the problem of locating test animals that contain no DDT. This assumption, however, may be questioned. Few measurements have been made of these chemicals in fish tissues in the past, but findings in the present study point toward the possibility of wider prevalence of DDT in trout than we have hitherto supposed. Field spray programs involving DDT were carried on in Montana and Wyoming, and fish from waters in sprayed areas were chemically analyzed to determine amounts of DDT in the fish. This report summarizes some of the general findings.

THE STUDIES

The spray projects were undertaken for the control of spruce budworm in coniferous forests

in Montana and northern Wyoming. The work was sponsored by the U. S. Forest Service and the U. S. National Park Service; fishery studies were carried on by these agencies, the U. S. Fish and Wildlife Service, and the Montana Department of Fish and Game. Facts about DDT and fish were collected in connection with the spray program of 1956 in streams of the Beaverhead National Forest (Cope and Park, 1957); a more extensive program of collection and chemical analysis of fish samples from the Yellowstone River system was carried on in 1957 and 1958 following the spraying in and around Yellowstone National Park in 1957.

In both programs the DDT was applied at the rate of one pound per acre, with an average of approximately one-quarter pound per acre reaching the ground and the water. Brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarki*) for chemical analysis were caught alive and were held in live cars during and after the spraying on the Beaverhead National Forest. The fish were killed and held in Bouin's fixative and then transferred to ethyl alcohol. Rocky Mountain whitefish (*Prosopium williamsoni*), cutthroat trout, rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), and longnose dace (*Rhinichthys cataractae*) from the Yellowstone River drainage were captured alive by shocking or by hook and line, and preserved by freezing. The fish from the Beaverhead were dissected, and individual tissues analyzed for DDT. The fish from Yellowstone were ground up in their entirety, blended, and the resultant material analyzed. In the case of the 1957 fish from Yellowstone, analysis was done by one laboratory for DDT and DDE; the 1958 fish were analyzed in another laboratory for DDT alone. Because of the fact that three laboratories were involved, and because of some lack of consistency in readings of different replications, we do not place complete reliance on all measurements. However, the trends in the data are of considerable importance and suggest lines of investigation that should be pursued.

RESULTS OF ANALYSES

Storage of DDT in tissues

Brook and cutthroat trout exposed to DDT in Trapper and Canyon Creeks on the Beaverhead National Forest in the summer of 1956 were dissected and five tissues chemically analyzed for DDT. DDT was found in visceral fat in all

fish from which it could be isolated, and in greater amounts than in any other tissue. Kidney ranked second in concentration of DDT, followed by pyloric caecum and brain. No trace was found in liver tissue. Differences between species were not established in this preliminary work.

Storage of DDT in whole fish

Analysis for DDT and its derivatives in blended samples of whole fish collected from the Yellowstone River drainage provided further important facts.

The DDT was applied from July 10 to 21, 1957. Thirty-three lots of fish from the drainage were collected from July 19 to September 25 and analyzed for DDT and DDE. Every sample of fish contained DDT, and all but four contained DDE. Some fish came from waters within the spray area, while others were taken from the Yellowstone River at stations below the spray area, the lowermost station being 85 miles downstream from the closest point of DDT deposit. Where more than one species were taken from one station, whitefish consistently contained more DDT and DDE than did the trouts. Cutthroat, rainbow, and brown trout from the same areas contained approximately the same amounts of DDT and DDE. Cutthroat trout contained considerably more DDT than did longnose dace. Cutthroat trout from Buck Lake had greater concentrations of DDT in their bodies than did the same species in streams, except those from two small tributary streams known to have been very heavily sprayed. Trout and whitefish from downstream stretches of the Yellowstone River contained DDT in about the same amounts as those upstream nearer the spray areas. In the Yellowstone River, fish taken in September averaged as much DDT as those taken in August.

Fish were collected from these same stations in the Yellowstone drainage from late fall of 1957 through June of 1958. These fish were analyzed for DDT, but not DDE, by another laboratory. They represented parts of the same populations as those collected in the summer of 1957 and, again, contained DDT. Here again, whitefish generally had more DDT than did the trout, and no obvious differences between species of trout were apparent. Downstream stretches of the Yellowstone River yielded fish with as much DDT in their tissues as did the

sections near the spray area. Collections in mid-winter and in the following June contained DDT in smaller amounts than did those of the late summer of 1957.

A series of 15-inch trout were collected as uncontaminated control fish from Pelican Creek in Yellowstone National Park on June 1, 1958. These fish were selected as controls because of the remote location of the stream, about 30 miles from the nearest spruce budworm spray area. To swim from the treated area, the fish would have had to ascend the Upper Falls of the Yellowstone, a barrier measuring 109 feet in height. This would have been impossible. There are no records of the use of DDT near Pelican Creek or contiguous waters. Yet, of the six control fish analyzed, all six were reported as positive for DDT. As a check on the reliability of the chemical analysis, other preserved trout tissues from the same lot of control specimens were subjected to bioassay with sensitive house-fly larvae. These results also indicated the presence of DDT in the control fish, and in almost the same amounts as those analyzed chemically.

In a search for fish without DDT, the chemists obtained rainbow trout from a fish hatchery whose water supply was from a deep well, and in an area with no record of the dissemination of DDT. The trout were found to contain DDT. Two species of marine fish were then purchased in a market and tested chemically; both groups had DDT in their bodies.

DISCUSSION

The findings on DDT concentrations in tissues are in agreement with the results reported by Burden (1956), who analyzed tissues of *Synodontis schall* and *Labea* sp., which had apparently been killed by DDT in Khartoum, Africa. Adipose tissue and fatty visceral tissues had retained the heaviest concentrations, while gills and muscles bore small amounts.

Comparison of the present information with that from the higher vertebrates shows general agreement. In rats and rabbits (von Oettingen, 1955), after administration of the chemical orally, intravenously, and intraperitoneally, fat consistently held the greatest amount of DDT, and nervous tissues contained relatively low densities. Bryson, et. al. (1950) determined that a similar pattern prevailed in chickens fed DDT in their diet.

The verification of the results of chemical analysis by the fly larva bioassay method in our control trout has helped to dispel doubts about the validity of the chemical technique. Considerable variation in DDT content as measured chemically from fish to fish in the same population had raised questions about the dependability of results. It is recognized that the Schechter-Haller reaction, the standard method for this determination, calls for extreme caution and attention in the laboratory, and usually demands special techniques for the removal of interfering substances. It gave much relief to have this substantiating evidence, since a basic requirement in this kind of study is to have an accurate, sensitive method for measuring amounts of toxicant. Even with a reliable test available, it becomes obvious from the present data that we must use a statistical basis for interpretation. The variation already measured within sets of replications suggests that individual differences to toxicants and in their retention in the animal body will require sound statistical planning and interpretation for future investigations.

It is hoped that an extensive program for measuring levels of toxicants in fish tissues can be inaugurated, since several important questions about effects on fish are related to types and amounts of pesticides retained in tissues. One matter to be explored is the relationship between this storage and morbidity and mortality in various environmental conditions. It is not enough to know how much toxicant will kill fish through acute toxicity; we must know about the role of storage in the creation of morbid conditions over long periods. We must know about length of exposure in relation to the amount stored in tissues, and when storage begins in relation to the amounts taken into the body. We should understand the mechanism of detoxification in the fish body in relation to the amounts retained. It is also significant to learn about storage and release from storage in relation to effects on growth, on reproduction, on behavior, and on genetics. If these aims are desirable, it is obvious that facts about the holding of toxicants in the tissues of fish are absolutely essential to a knowledge of the effects of these chemicals on the fish.

Another point of importance in this subject is the human ingestion of fish containing DDT. Hayes, et. al., demonstrated the relationship of meatless and ordinary diets to the amount of DDT and DDE in human fat. Undoubtedly most

of the DDT held in human tissues in this country comes through ingestion of fats from beef, pork, and mutton. If DDT is more prevalent in fish than we had formerly supposed, here is one more source of DDT for humans, both through

the use of sport-caught fish and through those purchased on the market. As the use of large-scale chemical control projects continues to grow, so may the gradual accumulation of toxicant in the human body increase.

REFERENCES

Bryson, J. J., C. I. Draper, J. R. Harris, C. Biddulph, D.A. Greenwood, L. E. Harris, W. Binns, M. L. Miner, and L.L. Madsen. 1950. DDT in eggs and tissues of chickens fed varying levels of DDT. *Amer. Soc. Hort.* 54:232-236.

Burden, E. H. W. J. 1956. A case of DDT poisoning in fish. *Nature.* 178:546-547.

Cope, Oliver B. and Barry C. Park. 1957. Effects of forest insect spraying on trout and aquatic insects in some Montana streams. U. S. Forest Service, Missoula, Montana, processed report. pp. 1-56.

Hayes, W. J. Jr., Griffith E. Quinby, Kenneth C. Walker, Jos. W. Elliott and William M. Upholt. 1958. Storage of DDT and

DDE in people with different degrees of exposure to DDT. *A. M. A. Arch, Indust. Health.* 18:398-406.

Pearce, G. W., A. M. Mattson, and W. J. Hayes, Jr. 1952. Examination of human fat for the presence of DDT. *Science;* 116:254-256.

Telford, H. S. and J. E. Guthrie. 1945. Transmission of the toxicity of DDT through the milk of white rats and goats. *Science;* 102:647.

von Oettingen, W. F. 1955. The halogenated aliphatic, olefinic, cyclic, aromatic, and aliphatic-aromatic hydrocarbons including the halogenated insecticides, their toxicity and potential dangers. U.S. Public Health Service, Government Printing Office. 431 pages.

THE TOXICITY OF ORGANIC PHOSPHORUS AND CHLORINATED HYDROCARBON INSECTICIDES TO FISH

Croswell Henderson, Q. H. Pickering, and C. M. Tarzwell - U. S. Department of Health, Education, and Welfare. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

ABSTRACT

Laboratory bioassays were conducted on some organic phosphorus and chlorinated hydrocarbon insecticides to determine their relative toxicity to fish and factors which may affect toxicity. The organic phosphorus compounds tested were EPN, Para-oxon, Parathion, TEPP, Chlorothion, Systox, Methyl Parathion, Malathion, Dipterex, OMPA, Guthion, Di-syston, and Co-ral. There was a wide range in the toxicity of the different compounds with 96 hour TL_m (median tolerance limit - concentration that kills 50 percent of the test fish) values ranging from .005 to 121 p.p.m. Several of these compounds were far more toxic to bluegills than to fathead minnows.

The chlorinated hydrocarbons (Endrin, Toxaphene, Dieldrin, Aldrin, DDT, Methoxychlor, Heptachlor, Lindane, Chlordane, and BHC) were generally more toxic than the organic phosphorus compounds. While bluegills were somewhat more sensitive to these compounds than other species, the magnitude was far less than with some of the organic

phosphorus compounds. All of the chlorinated hydrocarbons except BHC were extremely toxic to fish with 96 hour TL_m values generally below 0.1 p.p.m. Endrin was the most toxic with TL_m values ranging below 0.0005 p.p.m. The greater toxicity and the longer residual effects of this group make them particularly significant from the standpoint of effects on aquatic life.

Bioassays with a new carbamate insecticide, Sevin, indicated a low degree of toxicity to fish (TL_m 5.5 to 13 p.p.m.). For most of the compounds tested, water quality characteristics had little effect on toxicity and no correlations could be established between toxicity to insects, fish, and mammals.

The most promising approach to the solution of the insecticide problem with respect to fish appears to be the development of selective insecticides that are relatively non-toxic to fish or the addition of antagonistic agents for the reduction of toxicity.

INTRODUCTION

The greatly expanded use of organic insecticides has created new problems in water pollution. In addition to direct use in agriculture for protection of crops, some insecticides are applied over widespread areas for control or eradication of damaging pests, e.g., mosquito control, fire ant eradication, forest insect control. Direct application to surface waters and runoff or drainage reaching them from treated land areas may have an adverse effect on use of the water for fish and wildlife and for domestic and agricultural water supplies. To measure and evaluate the pollutional effects of insecticides, research on various phases of the insecticide problem was undertaken at the Sanitary Engineering Center, including an evaluation of the comparative toxicity of various insecticides to fish and investigation into the major factors which may affect toxicity. Such information would be of value in the selection of insecticides

for various insect control purposes.

This summarizes previously reported information on the toxicity of organic phosphorus (Henderson and Pickering, 1958) and chlorinated hydrocarbon (Tarzwell and Henderson, 1957; Henderson, Pickering, and Tarzwell, 1959) insecticides. Results of recent studies on the toxicity of some new organic phosphorus insecticides (Co-ral, Di-syston, and Guthion) and a new carbamate insecticide (Sevin) are presented. Suggestions are made for needed research.

BIOASSAY METHODS

Bioassay methods, facilities, and equipment are described in detail by Doudoroff, et al (1951) and Henderson and Tarzwell (1957). Salient features of the methodology as applied to the insecticide toxicity studies are repeated here. The method consists of preparing various concentrations of an insecticide in a selected

dilution water, adding the test fish, and observing their reactions for a definite time. For ease in plotting and interpreting results, test solutions are prepared with concentrations in a logarithmic series such as 10, 5.6, 3.2, 1.8, and 1.0 p. p. m.

As these chemicals were of unknown toxicity, small-scale exploratory tests were made to determine the approximate toxic range. Test solutions were prepared over a wide range of concentrations e. g., 100, 10, 1.0, 0.1 p. p. m. Two fish were added to two liters of each concentration in 6-1/2 inch diameter, 1-gallon widemouth glass bottles. Observations for a short period (overnight) indicated test concentrations necessary for full-scale experiments.

In the full-scale tests, ten fish were used in each concentration. For all species except guppies, five fish were added to 10-liter duplicate samples in 5-gallon widemouth glass bottles, 10 inches in diameter. Tests with guppies were made in 1-gallon glass bottles, using five fish in 2 liters of duplicate samples. The intermediate tested concentrations were dependent upon information obtained from the exploratory tests. For example, if fish were killed in concentrations of 10 p. p. m. and not in 1 p. p. m., intermediates were set up within this range e. g., 10, 5.6, 3.2, 1.8, and 1.0 p. p. m. of insecticide.

Two of the fish species used in the bioassays, fathead minnows (*Pimephales promelas*) and bluegills (*Lepomis macrochirus*), were wild native species raised in outdoor ponds at the State Fish Hatchery at Newtown, Ohio. The other two were so-called common household species, goldfish (*Carassius auratus*) and guppies (*Lebistes reticulatus*). Goldfish were obtained in uniform lots from a commercial fish farm and guppies were raised in our laboratories. Fathead minnows, bluegills, and goldfish were of similar size, ranging in length from 1-1/2 to 2-1/2 inches and in weight from 1 to 2 grams. Guppies were approximately six months old, 3/4 to 1 inch long, and weighed from 0.1 to 0.2 grams. All of these species were easily maintained in the laboratory and were highly satisfactory for bioassay work.

Two dilution waters were used: (1) soft water prepared in the laboratory by mixing 95 parts of distilled, demineralized water and 5 parts of a natural spring water; (2) hard water, a natural

limestone water obtained directly from springs. Before use, these waters were adjusted to the test temperature and aerated vigorously for about one hour to bring dissolved gases to near equilibrium with the atmosphere. At time of use, the average characteristics of these waters were as follows:

	Dissolved Oxygen ppm.	pH	Alka- linity ppm.	Hard- ness ppm.
(1) Soft Water	8.0	7.4	18	20
(2) Hard Water	8.0	8.2	360	400

Fresh preparations of the compounds or formulations, usually from 0.001 to 1.0 percent (depending on the solubility and toxicity) in acetone or water, were made up and computed quantities added directly to the test aquaria. Fish were then added and their reactions observed intermittently during the test period. All bioassays were conducted in a constant temperature room at 25° C.

Physical and chemical determinations (dissolved oxygen, pH, alkalinity, acidity, and hardness) were made on each test concentration initially and after fish mortality or at the completion of the test. This was done primarily to detect low dissolved oxygen levels, and control them if necessary, and to determine other conditions which may affect toxicity.

This type of bioassay is designed so that artificial aeration or oxygenation is not normally required when using chemicals having little or no oxygen demand. Absorption of atmospheric oxygen by the exposed water surface is usually adequate for fish requirements during the test period. However, the addition of acetone (used as a solvent for some tested materials) apparently increased biooxidation, causing a slight oxygen depletion in some test solutions. When needed, pure oxygen was added in the form of large bubbles at a slow rate to maintain dissolved oxygen at a satisfactory level.

Fish reactions were observed over a 96-hour period. From the mortality in different concentrations, 24-, 48-, and 96-hour TL_m (median tolerance limit) ^{1/} values were obtained, by

^{1/} The median tolerance limit is the concentration of a chemical in dilution water which causes 50 percent mortality of the test fish.

straight-line graphical interpolation from points representing percent survival of fish and log concentrations of insecticides which bracketed the 50-percent survival point. The 96-hour TL_m values, obtained by the above procedure, were used as the basis for direct comparison of the toxicity of the various insecticides.

ORGANIC PHOSPHORUS INSECTICIDES

Bioassays were made on ten organic phosphorus compounds, now in use or proposed for use as insecticides, to determine their comparative toxicity to fish (Henderson and Pickering, 1958). Different dilution waters and different species of fish were used in the toxicity evaluation and an attempt was made to correlate fish toxicity data with available mammalian toxicity data. Among the compounds tested were organic phosphates, thiophosphates, and phosphonates. Most of the compounds were obtained from manufacturers in the purest available form. As some of the compounds are not water soluble, it was necessary to use an organic solvent in preparing the test concentrations. Acetone was the solvent selected because it is relatively nontoxic (96-hour TL_m for fathead minnows - 11,500 ppm.) and readily miscible with water.

In most of the bioassays, only minor increases in fish mortality were observed between the 24- and 96-hour periods, as some of these materials hydrolyze readily to less toxic materials. In solutions of TEPP, one of the most rapidly hydrolyzed (50 percent in 6.8 hours), no fish mortality occurred beyond the 24-hour period.

Two notable exceptions, however, were Dipterex and OMPA which, while relatively less toxic than the other compounds, caused a considerable increase in fish mortality between the 24- and 96-hour periods. This increase may be partially explained by the fact that OMPA is slowly hydrolyzed (half-life, 100 years in neutral water) and that Dipterex, while readily hydrolyzed, is converted by mild alkali to the water insoluble and highly toxic O, O-dimethyl O-2-2-dichlorovinyl phosphate.

It is not known what may be the effect of exposure for a longer period or of continuously renewed solution. However, 96 hours appeared to be an inadequate period to obtain valid toxicity

data for such compounds as OMPA and Dipterex. Some preliminary experiments with parathion in a continuously renewed solution indicated no greater toxicity than that obtained in the previously described static bioassays.

The phosphates, para-oxon and TEPP, were among the most toxic of the compounds tested. The thiophosphates were somewhat less toxic, with parathion the most and malathion the least of this group. Some difference was found in the toxicity of the parathion samples from different manufacturers, with one sample approximately twice as toxic as the other. OMPA was considerably less toxic than compounds in either of the above groups. The two phosphonates were greatly different, with EPN among the most toxic and Dipterex among the least toxic of any of the compounds.

During the course of the bioassays, physical and chemical characteristics of the test solutions, such as dissolved oxygen, pH, alkalinity, and hardness, were not greatly altered from those of the dilution waters. Dissolved oxygen values remained between 4 and 8 ppm. in all test concentrations of all compounds during the 96-hour period. Apparently, there was little or no oxygen demand from these materials in the concentrations tested. In the higher concentrations of OMPA and Dipterex, the pH levels were reduced about one unit but in all cases remained between 6.5 and 8.5. Levels of both oxygen and pH were well within limits expected to support the test fish.

The physiological reaction of the fish was somewhat similar for most of these compounds; however, the response time varied considerably. Usually, the first noticeable change was a darkening of the skin, followed by a period of high excitability with body tremors, and then complete loss of equilibrium. Sometimes death did not occur for many hours after equilibrium was lost. This response was similar to that observed when working with some of the chlorinated hydrocarbon insecticides.

A response characteristic of the organic phosphorus compounds, not observed with other chemicals, was the extreme forward position of the pectoral and pelvic fins when the fish were affected.

Effects of Different Dilution Waters

Because insecticides enter different types of water, and since the toxicity of many chemicals is dependent upon receiving water characteristics (pH, alkalinity, hardness, etc.) tests were made to determine major differences in the toxicity of organic phosphorus compounds when using different dilution waters. The soft and hard waters used in the bioassays encompass the pH, alkalinity, and hardness range of most natural waters.

A direct comparison of the toxicity of the compounds tested in soft and hard water, based on p.p.m. of active ingredient, is shown in Table 1. While it might be expected that some of these compounds would be somewhat less toxic in hard water, due to increased hydrolysis rates in the more alkaline media, the results do not bear this out. Some were slightly less toxic in hard and some in soft waters, with no definite pattern established. Most of the results were within the range of experimental error that may be expected in bioassays when using ten fish. Dipterex was the only compound to show a much greater toxicity in hard water, due possibly to the more rapid breakdown to toxic products in the more alkaline waters, as discussed previously. These experiments indicate that the toxicity of most organic phosphorus compounds would not differ greatly in different receiving waters.

The values given in Table 1 for malathion and EPN were obtained from bioassays with formulations (emulsible concentrate and wettable powder, respectively) rather than technical grade compounds. Later work with technical malathion has indicated that these TL_m values

are too low and that at least part of the toxicity was attributable to the xylene solvent (96-hour TL_m - 24 p.p.m. in both hard and soft waters). Bioassays with technical malathion gave 96-hour TL_m values of 17 and 26 p.p.m. respectively in hard and soft waters with fathead minnows.

Toxicity to Different Species of Fish

Results of bioassays with parathion and TEPP indicated that bluegills were somewhat more sensitive to organic phosphorus compounds than fathead minnows. Additional work in this laboratory, however, has shown a much greater difference in species sensitivity to some other organic phosphorus insecticides. The 96-hour TL_m value for an acetone solution of technical malathion to bluegills in soft water was 0.095 p.p.m. as compared to 26 p.p.m. for fathead minnows, a difference of over 270 times. There was no difference in the toxicity to bluegills of acetone solutions and emulsible concentrates. The difference in species sensitivity was also pronounced with some of the newer organic phosphorus insecticides as explained in a later section of this paper.

Comparative Toxicity to Fish, Insects and Mammals

Comparative toxicity values for the organic phosphorus compounds to fathead minnows, houseflies, and white rats are shown in Table 2. As the route of administration is different, the numerical values for the different animals would not be directly comparable. However, the values give an indication of the insecticidal efficiency of the compound in relation to its possible effects on fish life and its potential danger to humans or animals from drinking water and food-stuffs.

Table 1. Comparison of the toxicity of organic phosphorus compounds to fathead minnows in soft and hard waters. (From Henderson and Pickering, 1958)

Compound	Percent active ingredient	96-hour TL _m	
		p.p.m active ingredient	
		Soft water	Hard water
Para-oxon	100.0	0.33	0.25
TEPP	100.0	1.7	1.0
Parathion No. 1	99.0	1.4	1.6
Parathion No. 2	96.5	2.7	3.6
Methyl parathion	80.0	8.3	7.5
Chlorothion	98.0	3.2	3.2
Systox	92.0	3.6	4.2
Malathion	57.0	12.5	12.5
OMPA	90.0	121.0	135.0
Dipterex	99.0	180.0	51.0
EPN	25.0	0.20	0.25

Table 2. Comparative toxicity of organic phosphorus insecticides to fish, insects, and mammals (From Henderson and Pickering, 1958).

Compound	Fathead minnows 96 hr TL _m ppm.	<i>M. domestica</i> Topical LD ₅₀ microgram/ gram	White rats Oral LD ₅₀ milligrams/ kilogram
EPN	0.20	1.9	12-40
Para-oxon	0.33	0.5	3-3.5
Parathion	1.4	0.9	13.0
TEPP	1.7	-	2.0
Chlorothion	3.2	16.5	880.0
Systox	3.6	-	6.2
Methyl parathion	8.3	1.0	14-42
Malathion	12.5	28.0	1375.0
OMPA	121.0	-	10.0
Dipterex	180.0	-	630.0

It is apparent from the table that there is no definite correlation in the toxicity of these compounds to fish, insects, and mammals. Perhaps this suggests that experimentation with other laboratory animals cannot indicate possible effects of these compounds on fish.

CHLORINATED HYDROCARBON INSECTICIDES

Bioassays were made on ten chlorinated hydrocarbon insecticides now extensively in use in insecticidal operations. Four different species of fish and two dilution waters with widely different characteristics were used in the toxicity evaluations (Henderson, Pickering, and Tarzwell, 1959).

The insecticides were obtained in their purest available form from manufacturers. All samples were either technical grade or reference standard material. Because these compounds are practically insoluble in water, it was necessary to use an organic solvent to obtain proper distribution for the bioassay test solutions. Acetone was the selected solvent as it is relatively nontoxic to fish and readily miscible with water.

In practically all of these bioassays fish mortality increased between the 24- and 96-hour periods. In a few experiments, which were allowed to remain for periods of ten days, additional fish mortality occurred. Further experiments in which fathead minnows were exposed

for twenty days to continuously renewed solutions of DDT and endrin showed that toxicity was approximately twice (TL_m value half) that obtained in 96-hour static experiments. These compounds apparently have a cumulative or chronic effect on fish.

During the course of the bioassays, physical and chemical characteristics of the test solutions (dissolved oxygen, pH, alkalinity, and hardness) were not greatly changed from those of the dilution water. While dissolved oxygen was slightly decreased in a few test solutions (attributed to the acetone solvent), sufficient oxygen was added to maintain levels of at least 4 ppm.

Physiological reactions of the test fish were somewhat similar for all of the compounds tested except BHC. The reaction time to most of the compounds, even in the highest concentrations, was much slower than has been observed with many other toxic compounds. In high concentrations the first visible effect occurred after 30 to 60 minutes exposure while in lower concentrations a much longer time was required. Generally, a brief period of high excitability, during which the fish swam rapidly on the surface around the edge of the test aquaria, was followed by alternate periods of muscular spasms resulting in short jerky movements and then by short quiescent periods accompanied by partial loss of balance. This response was followed by complete loss of equilibrium with the fish swimming on their backs in short jerky movements on the water surface in a circular pattern around the edge of the test jar. Death followed after varying periods, sometimes as long as 24 hours or more. A swelling in the abdominal region was observed, which was especially pronounced in fathead minnows. The fish also appeared somewhat lighter in color than the controls. Fish exposed to BHC did not react characteristically but slowly sank to the bottom of the aquaria and gradually expired.

Toxicity in Different Dilution Waters

As with the organic phosphorus compounds, bioassays were conducted with two dilution waters different in pH, alkalinity, and hardness but similar in other characteristics to determine the influence of these qualities on the toxicity of the chlorinated hydrocarbon insecticides.

The soft and hard waters used are described in the section on Bioassay Methods.

The comparative 96-hour TL_m values of the insecticides for fathead minnows in soft and hard waters are shown in Table 3. All values are reported as parts per billion (micrograms/liter) of active agent, computed from the percentage values shown in the Table. Most of the toxicity values in the two types of waters are in close agreement, well within the range of experimental error that may be expected in bioassays. Two of the compounds, endrin and chlordane, appear to be slightly more toxic in soft water, while heptachlor, toxaphene, and methoxychlor are apparently somewhat more toxic in hard water. On the basis of the results, it may be concluded that pH, alkalinity, and hardness (within the range tested) have no major effect on the toxicity of the chlorinated hydrocarbon insecticides to fish. Observations during these studies also indicate that changes in dissolved oxygen levels between 3 p. p. m. and saturation have little or no effect on their toxicity. While temperature and turbidity have been reported to affect the toxicity of some insecticides, these factors were not evaluated.

Table 3. Comparative toxicity of chlorinated hydrocarbon insecticides to fathead minnows in different dilution waters (From Henderson, Pickering, and Tarzwell, 1959).

Insecticide	Percent active agent	96 hour TL_m ppb. (micrograms/liter) active agent	
		Soft water	Hard water
Aldrin	88.4	33.0	28.0
Dieldrin	90.0	16.0	16.0
Endrin	91.0	1.0	1.3
Chlordane	100.0	52.0	69.0
Heptachlor	72.0	94.0	56.0
Toxaphene	100.0	7.5	5.1
DDT	76.0	32.0	34.0
Methoxychlor	100.0	64.0	35.0
Lindane	100.0	62.0	56.0
BHC	15.5	2300.0	2000.0

Toxicity to Different Species of Fish

The direct comparative 96-hour TL_m values for the ten chlorinated hydrocarbon compounds to four species of fish are shown in Table 4. All values are reported in parts per billion (micro-

grams/liter) of the pure compounds computed from the percentage of compound in the technical grade or reference standard material. All of the values are based on bioassays conducted under carefully standardized conditions using soft water as the diluent at a temperature of 25°C. Many are averages of two or more replicate experiments.

Endrin was by far the most toxic of the insecticides to all species of fish. In fact, it is the most toxic chemical that has been tested in this laboratory. The very closely related compounds, aldrin and dieldrin, were considerably less toxic, showing that a slight change in chemical structure can greatly change the degree of toxicity. Toxaphene was the second most toxic insecticide, followed by dieldrin, aldrin, and then DDT. Heptachlor, chlordane, methoxychlor, and lindane were only slightly less toxic than DDT.

It is difficult to make generalizations concerning the toxicity of a group of compounds, regardless of how closely they are related. Each compound has its individual characteristics and may or may not have identical physiological effects on an organism. Thus the relative toxicity to species may not be the same, even for very closely related compounds. This fact is borne out by a careful examination of the values given in Table 4.

Bluegills are generally more sensitive to the chlorinated hydrocarbon insecticides than the other species. Compared with fathead minnows, their sensitivity is approximately equal to two of the compounds, is two or three times greater to most, and is about five times greater to one compound. Fathead minnows in turn are more sensitive to most of the compounds than goldfish and guppies. While there is no definite relationship between the sensitivity of goldfish and guppies, goldfish may be considered slightly more sensitive to the whole group of compounds. Even such closely related compounds as dieldrin and endrin, chlordane and heptachlor, and DDT and methoxychlor do not necessarily give similar toxicity relationships. All of the compounds tested, except BHC, would be considered highly toxic to fish and were toxic to native species in concentrations of less than 100 p. p. b. (0.1 p. p. m.).

Table 4. Comparative toxicity of chlorinated hydrocarbon insecticides to different species of fish in soft water (From Henderson, Pickering, and Tarzwell, 1959).

Insecticide	96-hour TL _m (median tolerance limit) p. p. b. (micrograms/liter) active agent			
	Fatheads	Bluegills	Goldfish	Guppies
Aldrin	33.0	13.0	28.0	33.0
Dieldrin	16.0	7.9	37.0	22.0
Endrin	1.0	0.60	1.9	1.5
Chlordane	52.0	22.0	82.0	190.0
Heptachlor	94.0	19.0	230.0	107.0
Toxaphene	7.5	3.5	5.6	20.0
DDT	32.0	16.0	27.0	43.0
Methoxychlor	64.0	62.0	56.0	120.0
Lindane	62.0	77.0	152.0	138.0
BHC	2300.0	790.0	2300.0	2170.0

Comparative Toxicity to Fish, Insects, and Mammals

Values for the concentration or dose of the various insecticides lethal to fifty percent of fathead minnows, houseflies, and white rats are shown in Table 5. The numerical values are not directly comparable because the route of toxicant administration is different. For fish, the values are for the concentration in the surrounding medium (water) to which the fish are exposed for 96 hours with possible absorption through the respiratory tract and body surface. The other values are for single doses administered externally or internally. However, the values provide a comparison of the insecticidal efficiencies of the compounds in relation to the

possible effects on aquatic life through exposure in water and the effects on mammals by ingestion of water or food. Such comparative values may be useful in the selection of an insecticide for a specific purpose while giving proper regard to its effects on drinking water supplies and on fish and wildlife.

The apparent lack of a definite relationship between the values for the different animals suggests that fish bioassays cannot be used to predict toxicity to mammals and that, conversely, mammal tests cannot be used to predict toxicity to fish. To determine the possible effects on fish and wildlife, both types of studies are necessary.

Table 5. Comparative toxicity of chlorinated hydrocarbon insecticides to fish, insects, and mammals (From Henderson, Pickering, and Tarzwell, 1959).

Insecticide	Fathead minnows 96 hour TL _m (milligrams/liter)	Houseflies Topical LD ₅₀ (micrograms/gram)	White rats Oral LD ₅₀ (milligrams/kilogram)
Endrin	.0013	-	17.8
Toxaphene	.0051	31.0	90.0
Dieldrin	.016	1.1	46.0
Aldrin	.028	1.6	67.0
DDT	.034	8-21	113.0
Methoxychlor	.035	-	6000.0
Heptachlor	.056	1.6	100.0
Lindane	.056	1.0	125.0
Chlordane	.069	4.0	335.0
BHC	2.0	-	1000.0

Toxicity of Different Formulations

Previous data (Henderson, Pickering, and Tarzwell, 1959) had indicated that for a few of the chlorinated hydrocarbon insecticides, acetone solutions were approximately equal in toxicity to commercial emulsible concentrates. As the exact composition of commercial formulations was not known, emulsible concentrates containing 20 percent by weight active agent, 74 percent xylene, and 6 percent triton emulsifiers were prepared in the laboratory. Because of their limited solubility in xylene, lindane and BHC concentrates were prepared containing 10 percent active agent. Water emulsions containing from .001 to 0.1 percent active agent (depending on toxicity) were prepared for addition to the test aquaria.

Bioassays were conducted on prepared emulsible concentrates of the ten major chlorinated hydrocarbon insecticides using bluegills as the test fish and both soft and hard dilution waters. Results of bioassays and a comparison with acetone solutions are shown in Table 6, expressed in terms of p. p. b. (micrograms/liter) of the pure compounds.

Emulsible concentrates were equally toxic in soft and hard waters. With few exceptions there were no major differences in the toxicity of emulsible concentrates and acetone solutions. Some of the emulsible concentrates were slightly more toxic and some less toxic than acetone solutions. The major difference was in DDT in which the emulsible concentrate was 2-1/2 times more toxic. Experiments with commercial emulsible concentrates of endrin, dieldrin, and chlordane indicated about the same toxicity as the prepared formulations. The degree of toxicity of these materials was such that the toxicity of xylene and triton would produce no major effect. Bioassays with xylene gave 96-hour TL_m values of 24 p. p. m. in both soft and hard water and the addition of triton emulsifier did not change the toxicity.

Additional experiments indicated that laboratory bioassays can not be performed satisfactorily with granules, dusts, or oil solutions of insecticide, but that these formulations are somewhat less toxic than acetone solutions or emulsible concentrates. While wettable powders could be satisfactorily used, in the few experiments conducted their toxicity was not greatly different from that of acetone solutions. Additional experiments with wettable powders are planned.

Table 6. Relative toxicity of chlorinated hydrocarbon insecticide formulations to bluegills.

Compound	96-hour TL _m (ppb. active agent)		
	Acetone solution	Emulsible concentrate	
	Soft water	Soft water	Hard water
Endrin	0.60	0.46	0.44
Toxaphene	3.5	4.4	4.6
Dieldrin	7.9	10.0	9.1
Aldrin	13.0	7.8	7.8
DDT	16.0	6.4	8.8
Heptachlor	19.0	22.0	18.0
Chlordane	22.0	45.0	38.0
Methoxychlor	62.0	40.0	40.0
Lindane	77.0	51.0	51.0
BHC	790.0	800.0	810.0

Runoff Study

In cooperation with the U. S. Department of Agriculture and the Atlanta Regional Office of the Public Health Service, studies were made to determine the toxicity and insecticide content of runoff from an area treated with dieldrin for white fringed beetle control (Tarzwell and Henderson, 1957). A six-acre grassy slope on the Lawson General Hospital grounds was treated with 50 pounds per acre of a granular dieldrin-attapulugus clay formulation, which represented an application of 4.66 pounds of dieldrin per acre. Rainfall intensity-frequency and the volume of runoff were measured and runoff samples collected for bioassay.

Bioassays indicated that runoff from the first rain following treatment was toxic at a dilution of one in three. Fish mortality in undiluted runoff from the third rain was less than 50 percent in 96 hours and a few fish exhibited characteristic physiological reactions when placed in runoff from the fourth rain.

Because chemical methods were considered inadequate at the time of this study, it was decided to use fish bioassays for estimating the dieldrin content of runoff from the treated area. A time of effect concentration curve was prepared by exposing fish to known concentrations of dieldrin. Using this curve, it was estimated that the composite sample of runoff from the first rain contained 0.13 p. p. m. of dieldrin. It is evident that runoff from a similar extensive area treated with dieldrin at comparable rates would adversely affect fish life.

Application Rates Which May Produce Fish Mortality

The 96-hour TL_m values of the chlorinated hydrocarbon insecticides to bluegills and the computed rates of application to achieve these concentrations in water three feet deep are shown in Table 7. The three-foot-deep value was selected because it approximates the average depth of many farm ponds and smaller streams and also because an acre three feet deep approximates one million gallons.

It can be seen that normal rates of application for insect control on land areas (1, 2, or more pounds per acre), if allowed to reach water surfaces, would be highly toxic to fish, at least for most of these compounds. Some would be highly toxic at application rates normally applied to water surfaces for mosquito control (0.1 or more pounds per acre). While information is lacking on the insecticide content of runoff waters from insecticidally treated land areas, runoff from areas treated with dieldrin and endrin has been found to be toxic to fish.

Previous work with DDT has indicated that concentrations that are toxic in aquarium experiments are not necessarily toxic under field conditions, although the differences are small. These differences have been attributed to absorption of the toxicant by soils and vegetation, incomplete mixing, etc. However, the TL_m values given in Table 7 are concentrations that produce 50 percent mortality of a moderately sensitive fish in a relatively short period. Other

fish or food organisms may be more sensitive and the time of exposure may be longer. Thus the concentration safe for aquatic life may be considerably less than the value given, possibly as little as one-fifth or one-tenth. The rates of application given in the table would probably cause fish mortality under most conditions and certainly could not be construed as safe for aquatic life. Considerable additional research is needed before reasonably safe concentrations or application rates can be established for the chlorinated hydrocarbon insecticides under all conditions.

COMPARATIVE TOXICITY OF ORGANIC PHOSPHORUS AND CHLORINATED HYDROCARBON INSECTICIDES

A comparison of the toxicity to fish of chlorinated hydrocarbon and organic phosphorus insecticides is shown in Table 8. All values were derived from bioassays conducted under identical experimental conditions using fathead minnows. Since most natural surface waters are moderately hard, the TL_m values obtained in hard water were selected for comparison. All results are reported on the basis of parts per million of the pure compound, computed from the percentage in the test material.

As can be seen from the Table, all of the chlorinated hydrocarbons except BHC are more toxic than the most toxic organic phosphorus compound under these experimental conditions. On the basis of these data it is apparent that the chlorinated hydrocarbon insecticides would be of considerably more significance than the organic phosphorus compounds from the standpoint of protection of aquatic life. Some of the organic phosphorus compounds also hydrolyze rapidly to nontoxic products and many do not have the long-term residual toxicity characteristic of the chlorinated hydrocarbons. However, other factors such as absorption by soils and vegetation, solubility, runoff characteristics, etc., may have a bearing on the effect of field application. These factors could best be checked in field-scale experiments. Also, recent studies have shown a much greater toxicity differential between species of fish for the organic phosphorus compounds. The use of a different test species may give an entirely different relative toxicity picture.

The fact that some organic phosphorus com-

Table 7. Amount of chlorinated hydrocarbon insecticide applied to water surface that may produce fifty percent fish mortality (From Henderson, Pickering, and Tarzwell, 1959).

Insecticide	96 hour TL_m	Pounds per acre applied to the surface of water 3 feet deep to reach the TL_m concentration
	ppb. (micrograms/liter) active agent	
Endrin	0.60	0.005
Toxaphene	3.5	0.03
Dieldrin	7.9	0.07
Aldrin	13.0	0.11
DDT	16.0	0.13
Heptachlor	19.0	0.16
Chlordane	22.0	0.18
Methoxychlor	62.0	0.51
Lindane	77.0	0.63
BHC	790.0	6.4

Table 8. Comparative toxicity of chlorinated hydrocarbon and organic phosphorus insecticides to fathead minnows in hard water (From Henderson, Pickering, and Tarzwell, 1959).

Chlorinated hydrocarbon		Organic phosphorus	
Insecticide	96-hour TL _m p. p. m. (mg/l) active	Insecticide	96-hour TL _m p. p. m. (mg/l) active
Endrin	0.0013	EPN	0.25
Toxaphene	0.0051	Para-oxon	0.25
Dieldrin	0.016	TEPP	1.0
Aldrin	0.028	Parathion	1.6
DDT	0.034	Chlorothion	3.2
Methoxychlor	0.035	Systox	4.2
Heptachlor	0.056	Methyl parathion	7.5
Lindane	0.056	Malathion	12.5
Chlordane	0.069	Dipterex	51.0
BHC	2.0	OMPA	135.0

pounds are extremely hazardous to humans and other mammals and are readily absorbed through the skin may, in many situations, overshadow the fact that they are less toxic to fish.

TOXICITY OF NEW INSECTICIDES

Bioassays were conducted on several recently developed and promising insecticides. Three of these were organic phosphorus compounds (Guthion, Disyston, and Co-ral) and one was a carbamate compound (Sevin). Following is a description of the technical grade materials and commercial formulations tested, including their chemical names, some pertinent properties, and their composition, which was obtained from manufacturers.

Guthion, technical

Chemical name: 0,0-dimethyl S-(4-oxo-1,2,3-benzotriazinyl-3-methyl) phosphorodithioate.

Properties: Dark brown waxy solid; soluble in water at approximately 1:30,000; soluble in many organic solvents.

Composition: 93 percent Guthion.

Guthion, spray concentrate, analytical standard

Properties: Dark brown liquid; readily emulsified in water; specific gravity-0.983.

Composition: 18.3 percent Guthion.

Di-syston, technical

Chemical name: 0,0-diethyl S-2 (ethylthio) ethyl phosphorothioate.

Properties: Clear, oily liquid; slightly soluble in water (1:40,000); soluble in virtually all organic solvents; specific gravity - 1.144.

Composition: 90 percent Di-syston.

Co-ral, technical

Chemical name: 0,0-diethyl 0-(3-chloro-4-methyl-7-coumarinyl) phosphorothioate.

Properties: Slightly brownish powder; essentially insoluble in water; limited solubility in organic solvents.

Composition: not known but assumed to be 100 percent.

Sevin, technical

Chemical name: 1-naphthyl N-methylcarbamate.

Properties: Light lavender solid; moderately soluble in organic solvents; less than 0.1 percent soluble in water.

Composition: 95% Sevin.

Sevin, wettable powder, 50W

Properties: Light lavender powder; readily suspended in water.

Composition: 50 percent Sevin; 50 percent inert ingredients.

Bioassay Results

A summary of bioassay results for the new insecticides is given in Table 9. Twenty-four, 48, and 96-hour TL_m values are shown for different species of fish and different dilution waters. All values are reported as parts per million by weight (milligrams per liter) of the compound or formulation described in the previous section.

In all of these bioassays, fish mortality increased between the 24- and 96-hour periods, indicating some accumulative or chronic effect. All of these compounds except Di-syston were relatively slow acting and there was a considerable period of time between initial effect and fish mortality. Physiological reactions of fish to these compounds (including the carbamate, Sevin) were quite similar to those described previously for organic phosphorus compounds.

Comparative Effects - Different Dilution Waters, Fish, and Formulations.

Comparative 96-hour TL_m values under different experimental conditions are shown in Table 10. All values are reported in p. p. m. by

weight (milligrams per liter) of the pure compound computed from its percentage in the technical grade material or formulation.

Although not great, there was an apparent difference in the toxicity of some of these compounds when using different dilution waters. Guthion was apparently more toxic in soft water and Di-syston and Sevin in hard water.

Co-ral was not toxic to fathead minnows in either water at maximum amounts remaining in water solution.

Bluegills were more sensitive to all of these compounds than fathead minnows (Table 10). The difference was very large (20 to 100 times) for the organic phosphorus compounds but only about twice for Sevin. This information along with previously reported information on organic phosphorus insecticides shows a highly variable species toxicity differential for this type of compound. Care must be used in the application of bioassay data, especially when different fish species are of concern. An experiment with Guthion (Table 9) indicated guppies were of approximately the same sensitivity as fathead minnows.

Table 9. TL_m values for new insecticide formulations.

Formulation	Dilution water	Kind of fish	TL_m mg/l formulation		
			24 hour	48 hour	96 hour
Guthion, technical, 93 percent active in acetone	Hard	Fatheads	0.38	0.34	0.17
	Soft	Fatheads	0.24	0.22	0.10
	Soft	Bluegills	0.011	0.0075	0.0056
Guthion, commercial, 18.3 percent emulsible concentrate	Hard	Fatheads	2.8	2.45	0.92
	Soft	Fatheads	1.8	0.75	0.68
	Hard	Bluegills	0.15	0.13	0.032
	Soft	Bluegills	0.092	0.077	0.030
	Soft	Guppies	1.8	1.2	0.63
Di-syston, technical, 90 percent active in acetone	Hard	Fatheads	3.9	3.9	2.9
	Soft	Fatheads	6.8	4.4	4.1
	Soft	Bluegills	0.090	0.070	0.070
Co-ral, technical, 100 percent active in acetone	Hard	Fatheads	>18.	>18.	>18.
	Soft	Fatheads	>18.	>18.	>18.
	Soft	Bluegills	1.4	1.2	0.18
Sevin, technical, 95 percent active in acetone	Hard	Fatheads	12.0	7.1	7.0
	Soft	Fatheads	>32.	20.	13.
	Soft	Bluegills	11.	11.	5.6
Sevin, commercial, 50 percent wettable powder	Soft	Fatheads	56.	42.	41.
	Soft	Bluegills	>18.	14.	11.

Table 10. Comparative toxicity of new insecticides. Different dilution waters, fish, and formulations.

Compound	96-hour TL _m (mg/l active agent)			
	Acetone solution		Emulsible concentrate	
	Fathead minnows		Bluegills Soft water	Bluegills Soft water
	Hard water	Soft water		
Guthion	0.16	0.093	0.0052	0.0048
Di-syston	2.6	3.7	.064	.077
Co-ral ^{1/}	>18.	>18.	.18	.18
Sevin	6.7	12.	5.3	5.5 ^{2/}

Prepared emulsible concentrates (xylene--triton) containing 20 percent Guthion, 20 percent Di-syston, and 5 percent Co-ral, and a 50 percent Sevin wettable powder gave 96-hour TL_m values quite similar to those obtained from acetone solutions (Table 10). A Sevin wettable powder was used because of the low solubility in xylene and the low toxicity of this material. The toxicity of xylene (96-hour TL_m - 24 p. p. m.) would have caused fish mortality before the Sevin in a concentrate containing 10 percent or less active agent.

Comparative Toxicity to Fish and Mammals

The 96-hour TL_m values for bluegills are compared with orally administered LD₅₀ doses for white rats in Table 11. As with other insecticides there is no apparent correlation between the toxicity of these materials to fish and mammals. The fact, however, that several of these compounds show a relatively low order of toxicity to both fish and mammals may be of significance in the selection of an insecticide for widespread application.

NEEDED RESEARCH

The TL_m values given in this paper should not be construed as safe concentrations of insecticides for aquatic life. They are concentrations which will produce fifty percent mortality of moderately sensitive fishes in a short

Table 11. Comparative toxicity of new insecticides to fish and mammals.

Compound	96-hour TL _m - mg/l Bluegills ^{3/}	Oral LD ₅₀ - mg/kg White rats ^{4/}
Guthion	0.0052	15. - 25
Di-syston	0.064	2.1 - 8.6
Co-ral	0.18	90. - 150.
Sevin	5.3	540.

time period under specified experimental conditions. They may be expected generally to produce fish mortality, but they can be higher or lower, depending upon the circumstances under which the insecticides are applied. Research is urgently needed, particularly with respect to factors which may influence toxicity.

Studies needed, some of which are currently in progress at the Sanitary Engineering Center, are the following:

- (1) Relative toxicity of different formulations.
- (2) Effects of long-term exposure.
- (3) Toxicity of runoff from insecticidally treated areas, with reference to different soil types, land cover, rainfall intensity and frequency, etc.
- (4) Relative toxicity to important warm and cold water fish species, including effects at

^{1/} Solubility in water less than 18 mg/l.

^{2/} Wettable powder.

^{3/} Standardized conditions - Soft water.

^{4/} Values from manufacturers' literature.

different life cycle stages and toxicity to major fish food organisms.

(5) Effects of other water quality characteristics, especially temperature, turbidity, and organic content.

(6) Development of antagonistic additives that reduce the toxicity to fish with little effect on insecticidal activity.

(7) Use of fish bioassay as an analytical tool for determining insecticide residuals. Identification of the toxicant by physiological response of fish.

Further research is also needed concerning the possible effects on human health and land and water uses. In progress at the Center are studies concerning mammalian toxicology, effectiveness of water treatment processes in removal of insecticides, identification by carbon absorption and infrared techniques, and effects on water-borne bacterial populations.

It is preferable and possibly essential that such investigations be made in the developmental stages of an insecticide rather than after its widespread application.

REFERENCES

Doudoroff, P., B. G. Anderson, G. E. Burdick, P. S. Galtsoff, W. B. Hart, R. Patrick, E. R. Strong, E. W. Surber and W. M. Van Horn. 1951. Bioassay methods for the evaluation of acute toxicity of industrial wastes to fish. *Sew. and Ind. Wastes*, 23, (11): 130-1397.

Henderson, C. and C. M. Tarzwell. 1957. Bioassays for control of industrial effluents. *Sew. and Ind. Wastes*, 29, (9): 1002-1017.

Henderson, C. and Q. H. Pickering. 1958. Toxicity of organic phosphorus insecticides to fish. *Trans. Amer. Fish Soc.*, 87: 39-51.

Henderson, C., Q. H. Pickering, and C. M. Tarzwell. 1959. The relative toxicity of ten chlorinated hydrocarbon insecticides to four species of fish. *Trans. Amer. Fish. Soc.*, 88, (1): 23-32.

Tarzwell, C. M. and C. Henderson. 1957. Toxicity of dieldrin to fish. *Trans. Amer. Fish. Soc.*, 86: 245-257.

SOME EFFECTS OF PESTICIDES ON MARINE ARTHROPODS AND MOLLUSKS

Victor L. Loosanoff - U. S. Fish and Wildlife Service
Bureau of Commercial Fisheries, Milford, Connecticut

ABSTRACT

Our interest in pesticides was principally concerned with their use in controlling aquatic forms which were either competitors or enemies of such commercial mollusks as oysters, clams and scallops. Perhaps one of the most important observations, which was made in our 1946 studies in this field, was that setting of barnacles on oyster collectors could be prevented if the collectors were treated with DDT, thus protecting recently set oysters against competition and overcrowding by barnacles. Within a few years this observation was of help to Britain's biologists and her oyster industry in combatting heavy fouling of oyster beds by the imported Australian species of the barnacle, Elminius modestus.

In continuing our work with pesticides we found many compounds which, either in solution or in bait, kill crabs. Many of the latter, especially the so-called green crabs, are among the most destructive enemies of commercial mollusks. Such relatively common insecticides as Guthion, Dipterex, Lindane, TEPP, Sevin, Dieldrin and many others were among the chemicals found. These chemicals also affected other related forms, such as shrimp, prawns, copepods, etc.

We also found that mollusks are far from being immune to the effects of some pesticides. For example, the larvae of the common American oyster, C. virginica, are strongly affected by the presence of DDT in sea water. In a concentration of 1.0 part per million of DDT in sea water the larvae died in four days. Even in a concentration of 1.0 part of DDT in 40 million parts of sea water the oyster larvae did not grow well.

From approximately 3,000 organic compounds which were "screened" at our laboratory during the last few years, we chose several to be incorporated in a formula which we devised to create so-called "chemical barriers" against the movements of oyster enemies, such as drills, starfish and crabs.

Our studies indicated that many pesticides are extremely toxic to aquatic forms and their indiscriminate use is unforgivable. Therefore, before any chemical is employed on a large scale for the control of terrestrial or aquatic animals, it is suggested that it be thoroughly evaluated by experienced biologists in terms of danger to other forms. In other words, a delicate balance between the constructive and destructive effects of a chemical should be critically evaluated.

As an introduction, I would like to emphasize that our original interest in pesticides was principally concerned with their uses in controlling undesirable aquatic forms which, in one way or another, either compete with or are direct enemies of commercial mollusks. Although our initial studies took place some time ago, 1946 to be exact, we still continue to regard pesticides as a tool which, if properly used, can help us develop more advanced and more effective methods of shellfish culture.

Our desire to use pesticides does not mean, of course, that we fail to realize the immense danger, by their indiscriminate use, to many forms populating aquatic basins, especially small, semi-enclosed bodies of water in the proximity of extensive farming districts, where pesticides may be widely used. We think, nevertheless, that certain compromises may be

reached, leading to the control of undesirable species without endangering the forms which should continue to exist. In other words, as in many complicated problems encountered in our age, successful solutions depend on well-planned, scientific research. In the aquatic environment with which we deal, the problems may often be even more complex than those on dry land, where control methods are somewhat easier to apply. Nevertheless, by pursuing solutions of these problems along well-defined lines and using original approaches, reliable scientific material may be accumulated providing us eventually with data on which dependable conclusions may be founded.

In this paper I shall offer only a few references to the work of others on the effect of insecticides on aquatic forms because a complete review here would be time-consuming and out of

place. Furthermore, many well-prepared articles of the achievements in this field are already available, several of them published by the members of the Robert A. Taft Sanitary Engineering Center. I shall merely mention some of our observations and consider them from two points of view; namely, as indicating progress in the control of undesirable aquatic forms, and as a reminder of the dangers of indiscriminate use of pesticides, without considering what havoc they may create in water communities if they gain entrance in sufficiently large quantities.

In describing our work we may begin by mentioning that, perhaps, one of our most important observations was made in 1946 when, in a series of field experiments, we found that setting of barnacles on oyster shells and other spat collectors could be prevented if the collectors were treated with a solution of DDT (Loosanoff, 1947). In a few years this observation, which at first appeared to be relatively unimportant, was of help to Britain's biologists and her oyster industry in combatting heavy fouling of spat collectors and oyster beds in general by setting of barnacles, especially Elminius modestus, which, during the war, was introduced into British waters from Australia (Waugh et al, 1952 and 1956). This, I believe, was the first, clear-cut demonstration of the advantage of the proper use of insecticides in oyster culture without endangering or radically changing the general conditions of the environment. Waugh and his associates also experimented with gamma isomer of benzene hexachloride (Lindane) and Dieldrin.

Soon after our work with DDT we began a new study, which is still in progress. It consists of a systematic "screening" of numerous compounds to find those that may be usable in controlling various molluscan enemies, such as drills and other boring gastropods, starfish and crabs. In these studies we are being generously helped by several chemical companies, especi-

ally the Niagara Chemical Division, Food Machinery and Chemical Corporation, which is supplying us with hundreds of samples. It is, of course, unavoidable that during these studies we have been using many pesticides, especially insecticides.

During the "screening" many chemicals were found that are extremely toxic to those shellfish enemies that belong to the phylum Arthropoda. Some of these substances were found to be effective in solution; some, as food poisons; while many can be effectively used either way (Loosanoff, Hanks and Ganaros, 1956). To ascertain the effectiveness of these substances within the group of marine Arthropoda, we used the following forms:

Rock crab	<u>Cancer irroratus</u>
Blue crab	<u>Callinectes sapidus</u>
Lady crab	<u>Ovalipes ocellatus</u>
Mud crab	<u>Panopeus herbstii</u>
Green crab	<u>Carcinides maenas</u>
Hermit crab	<u>Pagurus pollicaris</u>
Spider crab	<u>Libinia emarginata</u>
Common sand shrimp	<u>Crangon vulgaris</u>
Mantis shrimp	<u>Squilla empusa</u>
Copepods	(several species)
Horseshoe crab	<u>Limulus polyphemus</u>

The results showed that all these forms can be quickly affected and killed. Considering the relative positions of these animals within the phylum Arthropoda, it can be safely assumed that we already have a means of controlling most of the undesirable crustaceans which, in one way or another, endanger commercial mollusks.

Using the green crab, Carcinides maenas, as the test animal we found more than a hundred compounds that kill these crabs when incorporated in bait or in solution. A partial list of these compounds, many of which are insecticides, is given below:

<u>s</u> -Triazine, 2-amino-4-benzenesulfonamido-6-phenyl-	2-Butanone, thiosemicarbazone	Vulpinic acid
<u>m</u> -Dioxane, 5-methyl-5-nitor-2-styryl-	Dodecylamine, 1- <u>p</u> -tolyl-, hydrochloride	Propionitrile, 2-cyclohexylamino-2-methyl-
<u>m</u> -Dioxane, 5-ethyl-5-nitor-2-styryl-	1-Piperazinecarboxamide, N-ethyl-N, 4-dimethyl-4-oxide	Acetophenone, 2-phenyl-2-piperidino-, hydrochloride
Hydratroponitrile, B-cyclohexylamino-, hydrochloride	Benzene, propyl	Oleamide, N,N'-hexamethylenebix-
<u>m</u> -Dioxane, 2-(<u>p</u> -chlorophenyl)-5-methyl-5-nitro-	Carbanilic acid, <u>m</u> -chloro-, isophentyl ester	Carbamic acid, dithio (2-(2-thioxo-1-imidazolidinyl) ethyl)-, sodium salt, trihydrate
Hydratroponitrile, p-benzylamino-, hydrochloride	Cyclopentane, 1,2-dibromo-3-chloro-	
	Carbanilic acid, <u>m</u> -chloro-, pentyl ester	

Lindane, benzene hexachloride (gamma isomer)	Dipterex, O,O-dimethyl-2,2,2-trichloro-1-hydroxyethyl phosphonate	4-(4-Nitrophenylazo)-1-Napthol
2, 4-dichlorophenol	Dicaphon, O,O-dimethyl 0-(2-chloro-4-nitro phenyl) thiophosphate	Tris (stearoxymethyl) nitromethane
1, 1, 1-trichloro-3-nitropropanol-2	Parathion, O,O-diethyl-O-p-nitrophenyl thiophosphate	2-Nitro-2-ethyl-1, 3-propane diol di-propionate
2-thiazolidinethione	Di-Syston, O,O-diethyl, S-2-(ethylthio) ethyl phosphorodithioate	2-Dimethyl amino isobutyl octanoate
S-(2, 4-dichlorobenzyl) thiouronium chloride	Systox, O,O-diethyl-0-2-(ethyl-mercapto)-ethyl thiophosphate	5-Amino-2, 5-diethyl-2-methyl-1, 3-dioxane
4-chlorobenzyl chloride	Thimet, O,O-diethyl S-(ethyl-thiomethyl) phosphorodithioate	5-Nitro-5-hydroxymethyl-2-phenyl-1,3-dioxane
1, 4-bis (chloromethyl) benzene	Methoxychlor	Tris (stearoxymethyl) dimethyl amino methane
m-cresol	5-Nitro-5-ethyl-2-(1-ethyl-1-pentenyl)-1, 3-dioxane	Tris (octanooxymethyl) dimethyl amino-methane
o-cresol	Dilan (contains 21.3% Prolan and 42.7% Bulan with 16% related compounds plus 20% xylene)	2-Nitro isobutyl chloromethyl ether
1, 2-dichloro-4-nitrobenzene	Tris (2-nitro isobutyl) phosphate	Bis (2-amino-1, 2-dimethylpropoxy) methane
4-chloronitrobenzene	2-Nitro-2-ethyl-1, 3-propanediol dis-tearate	Bis (2-nitro isobutyl) phthalate
2, 5-dichloronitrobenzene	2-Nitro-2-methyl-1, 3-propanediol dis-tearate	5-Amino-5-hydroxymethyl-2-phenyl-1, 3-dioxane
Tetraiodofluorescein	Bulan Crystalline	2-Amino-1, 3-propanediol
1, 4-Dibromobutene-2	1, 1-Bis (2-aminoisobutoxy) butane	Bis (2-nitro isobutoxy) methane
3-Bromopropene	2-Chloro-1-nitro propane	5-Nitro-2-phenyl-1, 3-dioxane
4-bromophenacyl bromide	3-Dimethyl amino-1-methyl-1,5-dioxaspiro (5, 5) hendecane	Prolan Crystalline
4-nitrophenylhydrazine	5-Benzylamino-5-methyl-1, 3-dioxane	2-Nitro-1-phenyl-1-propane
phenacyl bromide	Tris (acetoxymethyl) nitromethane	3-Amino-3-methyl-1, 5-dioxaspiro (5,5) hendecane
2, 4-diisocyanatotoluene	5-Nitro-5-methyl-2, 2-diphenyl-1, 3-dioxane	Bis (2-aminoisobutoxy) methane
3-chlorophenyl isocyanate	Bix (2-nitro isobutoxy) phenyl methane	2-Methyl-1, 2-propane diamine
4-bromophenol	Sevin, N-methyl-1-napthyl carbamate	N'-Isopropyl-2-methyl-1, 2-propane diamine
2, 4, 6-Trichloroaniline	Pentachlorobenzyl chloride	5-Amino-5-methyl-1, 3-dioxane
1, 4-Dichlorobutene-2	2, 3-Dibromo-1, 4-dichlorobutene-2	DDT, 2, 2-bis (p-chlorophenyl)-1, 1, 1-trichloroethane
Paradichlorobenzene	4-Chlorophenyl allyl sulfide	
Orthodichlorobenzene	5-(4-Chlorobenzylidene)-3-methyl-2-thiothiazolidine-2, 4-dione	
Dimethallyl sulfide	"Roccal", a 50% concentrate of alkyl dimethylbenzyl ammonium chlorides	
Benzyl allyl sulfide		
3, 4-Dichlorobenzyl chloride		
Dimethallyl disulfide		
Phenyl allyl sulfide		
1, 4-Dichlorobutyne-2		
Guthion, O,O-dimethyl-S-(4-oxo-benzotriazino-3-methyl) phosphorodithioate		

Parallel with the development of methods for the control of crabs, which destroy oysters and clams, we found a simple way, by using comparatively common insecticides, such as Guthion, Dipterex, Lindane or TEPP, to control a variety of small crustaceans which often invade our open mass cultures of algae, such as *Chlorella*, and rapidly consume a majority of the algal cells (Loosanoff, Hanks and Ganaros, 1957).

At present we are especially interested in one compound, Sevin (1-naphthyl-N-methyl carbamate), which is relatively safe to mammals but, nevertheless, extremely toxic to arthropods. We have employed Sevin in a number of successful experiments and have distributed samples of it to several of our colleagues.

Continuing to think about protection of cultivated beds of commercial mollusks, we are developing a method to prevent undesirable species from re-invading clean clam and oyster beds from which enemies have been removed. Again, selecting from numerous compounds "screened" at our laboratory during the last few years, we chose several, some of them insecticides, to be incorporated in formulae which we devised to create so-called "chemical barriers" to stop the movements of shellfish enemies, such as boring gastropods, starfish and crabs. I am not at liberty at this time to go into the details of this method, but I may mention that we are quite certain of being on the verge of offering several variations of a cheap but effective method which will probably end the danger of invasion of cultivated molluscan beds by undesirable forms.

Thus, after long and tedious experimenting with the use of the chemicals, we may be now approaching the solution of the problem of controlling several of the most common and dangerous shellfish enemies. During these studies, however, we began to understand more clearly how extremely dangerous many of these substances are to useful aquatic forms. For example, we realized that in eliminating the green crab, which is among the chief enemies of shellfish, especially the soft clam of New England, lobsters may also be killed. Indiscriminate use of insecticides in Chesapeake Bay, where the blue crab is an important commercial species, would, of course, involve considerable risk. In the Gulf of Mexico commercial varieties of shrimp, especially their larvae, which

come close to the shore, have to be protected from mass extermination. We hope to solve these difficulties by finding specific poisons that will kill only certain animals and leave others unharmed. We already have had some promising results in this direction. Nevertheless, this is the opportunity to emphasize once more that before any chemical is used on a large scale for the control of terrestrial or aquatic animals, it should be thoroughly evaluated by experienced biologists in terms of its danger to other forms, as well as to human beings. In other words, a delicate balance between the so-called constructive and destructive effects of the same chemical on the general environment and animal communities should be critically evaluated before its use is generally permitted.

An experienced biologist will know that, although the use of insecticides may be more dangerous to aquatic arthropods than to other groups living in the water, because of the similarity of the nervous systems of terrestrial insects and those of crabs, shrimps, copepods, etc., the danger is not confined to this particular phylum. On the contrary, our preliminary studies, which we hope to extend during the next few years, have shown that mollusks are also far from being immune to the harmful effects of some of these substances. For example, my associate, Harry C. Davis, showed that larvae of the American oyster, *C. virginica*, kept in 1.0 part per million of DDT in sea water die within four days; in 0.05 p.p.m. their growth is almost completely stopped, and even in 0.025 p.p.m. the larvae do not grow well. This, of course, points to the dangerous conditions that may be created in many of our harbors and bays which receive a large quantity of fresh-water from watersheds treated with DDT.

It is erroneous, however, to assume that all insecticides are just as poisonous to oyster larvae as is DDT. This was again demonstrated when Davis found that larvae of oysters kept in a concentration of 1.0 p.p.m. of Dipterex or Parathion did not suffer greater mortality than did the controls, although the growth of the larvae was somewhat retarded. Nevertheless, at two lower concentrations, i.e., at 1.0 part per 20 or 40 million parts of sea water, the larvae did not significantly differ in size from the controls. It is interesting to mention here that when Guthion was used it caused no appreciable mortality or retardation of growth, even at

concentrations of 1.0 p.p.m. Larvae kept in 0.05 p.p.m. of Guthion actually grew faster than did those in untreated cultures. Perhaps the bactericidal action of Guthion, if such exists, was the factor responsible for the better larval growth. Similarly, clam larvae survived quite well although they grew somewhat slower than the controls at 1.0 p.p.m. of Lindane or 1.0 p.p.m. of Dipterex. Lower concentrations, i.e., 1:20,000,000 or 1:40,000,000, slowed growth of these larvae only slightly.

In concluding this short discussion I would like to mention once more that, while a great deal of work has been done to determine the effects of insecticides on terrestrial forms, we still know little about the effect of these substances upon aquatic forms. We should not con-

demn the use of these substances outright, however, because this obviously would be an irrational and illogical step. Instead, we should critically evaluate the desirability of their usage by comparing their constructive and destructive values. This can only be achieved by well-designed, systematic studies which, of course, will require a great deal of time, patience and ingenuity.

I wish to express my thanks to my former associates, James E. Hanks and Anthony E. Ganaros, who conducted the initial experiments, and to Lloyd W. Shearer and Clyde L. MacKenzie, Jr., who are presently working on this problem. Their cooperation has helped us to obtain extensive information, some of which is reported in this paper.

REFERENCES

Loosanoff, V.L. 1947. Effects of DDT upon setting, growth and survival of oysters. *Fishing Gazette*, 64, (4):94, 96.

Loosanoff, V. L., J. E. Hanks and A. E. Ganaros. 1956. Chemical control of shellfish enemies promising. *Natl. Fisherman*, 37, (11): 16, 40.

Loosanoff, V. L., J. E. Hanks and A. F. Ganaros. 1957. Control of certain forms of zooplankton in mass algal

cultures. *Science*, 125: 1092-1093.

Waugh, G. Duncan, F. B. Hawes and F. Williams. 1952. Insecticides for preventing barnacle settlement. *Annals of Applied Biology*, 39: 407-415.

Waugh, G. Duncan, and A. Ansell. 1956. The effect, on oyster spatfall, of controlling barnacle settlement with DDT. *Annals of Applied Biology*, 44: 619-625.

THE TOXICITY OF ORGANIC INSECTICIDES TO DAPHNIA

Bertil G. Anderson - Pennsylvania State University
University Park, Pennsylvania

Problems created by pollution multiply with each new chemical brought into commercial production. In order to determine how seriously the production of a new compound increases pollution problems a great many factors must be taken into consideration, among them is the toxicity to the organisms likely to be affected. A number of years ago I set about devising a simple method for using Daphnia magna as the test animal for toxicity determinations. Others before me had used Daphnia magna for such purposes. The chief difference between my procedures and those used by earlier workers was that I employed young animals of known age (Anderson, 1944).

Daphnia magna are the largest of the genus but even so they grow only to a maximum size of five mm. A great many can be reared in a small space. They have a relatively short life span, up to three months when they are reared at 20°C. Their culture is easy. They give birth to young before they are a week old and they continue to give rise to new broods every two to three days for the remainder of their lives. Records of over a hundred young in a brood are recorded. Each female may bear over a thousand offspring in her lifetime. All of the offspring from any female are genetically like the mother if produced parthenogenetically, and reproduction can be limited to parthenogenesis if the proper culture conditions are maintained. For these reasons, I believe that Daphnia magna is a good animal to use as a reference standard in the study of toxic materials.

The use of modern insecticides constitutes a threat to our fish and wildlife resources, as has been emphasized so impetuously during the preceding sessions of this conference. I have been interested in these and other toxic substances. I want to report on some experiments which have been carried out at Penn State to determine their toxicity thresholds (Boyd, 1957).

The methods employed for the experiments I am reporting are essentially the same as those described earlier (Anderson, 1944) except that: (1) the diluent was synthetic, being made from distilled and demineralized water to which 200 mg. NaHCO_3 , 224 mg. CaCl_2 , and 26 mg. K_2SO_4 were added per liter; (2) the animals were 12 ± 12 hr. old when placed in the test solutions; and (3) the temperature was 20°C. For further details see Boyd (1957).

A comparison of the immobilization concentrations given in Table 1 with those for other aquatic animals shows that different animals vary considerably in their susceptibility to these

Table 1. Estimated Concentrations Required to Immobilize Daphnia magna in 50 hours^{1/}

Compound	ppb
DDT	1.4
Methoxychlor	3.6
Chlorobenzilate	1400.
Parathion	0.8
Malathion	0.9
Diazinon	4.3
EPN	0.1
Aldrin	29.2
Heptachlor	57.7
Dieldrin	330.
Endrin	352.

^{1/}From Boyd (1957)

insecticides. Adequate comparisons are difficult unless the conditions under which the animals are exposed are identical. Even though conditions were different with respect to water and temperature the results of Boyd for DDT are the same as those reported by Anderson (1945). Fish are reported to be far more susceptible to many of these insecticides, especi-

ally endrin, than Daphnia magna. On the other hand Daphnia magna is far more susceptible to parathion. When we develop a better understanding of the modes of action of these compounds we will be in better position to explain the variations in the responses of the various species of animals to them.

REFERENCES

Anderson, Bertil G. 1944. The toxicity thresholds of various substances found in industrial wastes as determined by the use of Daphnia magna. Sewage Works Journal 16: 1156-1165.

Anderson, Bertil G. 1945. The toxicity of DDT to Daphnia.

Science 102:539.

Boyd, John. 1957. The use of Daphnia magna in the microbioassay of insecticides. Thesis, The Pennsylvania State University. 194 p.

TOXICITY OF VARIOUS HERBICIDAL MATERIALS TO FISHES

Carl E. Bond, Robert H. Lewis, and John L. Fryer - Oregon State College,
Corvallis, Oregon

Due to greater use of herbicides in modern land and water management, there are increased possibilities for contact of such chemicals with waters containing fishes. Contact may come about in the following ways: (1) use of chemicals as aquatic herbicides (2) accidental spray drift from treated land areas (3) runoff from treated lands (4) washing of spray equipment in waterways (5) discarding of excess chemicals from spray tanks into waterways.

The necessity of determining the toxicity of herbicides to fish is evident. Consequently, aquatic weed control research at the Oregon State College, has included studies on the toxicity of several chemicals commonly used as herbicides, or with possible use as herbicides, to certain game fish (Table 1).

Most of the formulations used in the experiments were donated by the manufacturing or distributing companies. Diuron, Fenuron and Monuron were received from E. I. DuPont de Nemours Co. Dowpon, Baron and Kuron were donated by the Dow Chemical Company. The American Chemical Paint Company supplied aminotriazole and ACP-M-569. The following were received from the companies designated: F-98, Shell Development Co.; Diquat, Plant Protection Ltd.; Endothal, Pennsalt Chemicals Corp.; Hyamine 1622, Rohm and Haas Chemical Co.; Omazene, Olin Mathieson Chemical Corp.; Simazine, Geigy Agricultural Chemicals; Phygon XL, U. S. Rubber, Naugatuck Chemical Division.

Fish used as test animals were fingerlings of the following species: coho salmon, Oncorhynchus kisutch (Walbaum); chinook salmon, O. tshawytscha (Walbaum); rainbow trout, Salmo gairdnerii Richardson; and the largemouth bass, Micropterus salmoides (Lacépède). Coho salmon and rainbow trout were obtained from the Alsea Trout Hatchery of the Oregon State Game Commission. Chinook salmon used were from

the McKenzie Salmon Hatchery at Leaburg. Largemouth bass were obtained from natural waters in the Willamette Valley.

The bioassay procedures as outlined by Doudoroff et al. (1951) were employed in most of the experiments. Bioassays were conducted in glass jars containing 15 liters of water. The methyl orange alkalinity of water pumped from Marys River for use in the experiments ranged from 41 to 71 p. p. m. during the periods of experimentation. The pH ranged from 7.4 to 7.7.

Ten test animals of approximately equal size were used per jar. Average fork lengths of largemouth bass used in the several experiments ranged from 55 to 68 mm. Coho salmon ranged from 59 to 78 mm.; chinook salmon 58 to 96 mm. and rainbow trout 83 to 89 mm. In order to obtain the mean lengths of animals used for each experiment all dead fish and 30 percent of all surviving fish were measured. Most experiments were conducted at a constant temperature of $20^{\circ} \pm 0.5^{\circ} \text{C.}$, although Acrolein was tested at 13°C. as well. All solutions were aerated during tests by compressed air or oxygen and solutions were not changed during the individual experiments. The effects of aeration and storage on the toxicity of several of the compounds were studied (Fryer 1957). Concentrations are given in terms of active ingredient.

In exploratory short-period exposure experiments, chinook salmon were exposed for 15 and 30 minutes to two concentrations each of arsenic trioxide, Baron, Kuron, Delrad, Phygon XL, copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), trichlorobenzene and acrolein. Concentrations tested approximated and exceeded those suggested for field use of the chemicals involved. In the short time exposure experiments, fish were placed into wire baskets and immersed in the test solutions for the appropriate period, then returned to untreated water and held under observation for 24 hours.

Table 1. List of chemicals studied in fish toxicity bioassays, with median tolerance limits for largemouth bass, chinook salmon and coho salmon.

Commercial, common or code name	Chemical name of active ingredient	Median tolerance limits in p. p. m. active ingredient					
		Largemouth bass		Chinook salmon		Coho salmon	
		24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.
ACP-M-569	(contains 3 amino-1, 2, 4-triazole)	--	--	185	155	--	--
Aminotriazole	3-amino-1, 2, 4-triazole	not toxic to 1000 p. p. m.		--	--	325	325
Baron	dalapon ester of 2, 4, 5-trichlorophenoxy ethanol	4.6	--	2.62	2.3	--	--
Dowpon	2, 2-dichloropropionic acid, sodium salt . . .	not toxic to 1000 p. p. m.		--	--	340	340
Diquat	1:1'ethylene-2:2' dipyridylum dibromide . .	--	--	29.5	28.5	--	--
Diuron	3-(3, 4-dichlorophenyl)-1, 1-dimethylurea . .	low toxicity in sol. range		--	--	33	16
Endothal	disodium 3, 6-endoxy-hexahydrophthalate . .	200	200	155	136	--	--
F-98	Acrolein	--	--	0.08	--	--	--
Hyamine 1622	p-diisobutyl phenoxy ethoxy ethyl dimethyl benzyl ammonium chloride monohydrate	--	--	--	--	57	53
Kuron	α (2, 4, 5-trichlorophenoxy) propionic acid	3.5	--	1.35	1.23	--	--
Monuron	3-(p-chlorophenyl)-1, 1-dimethylurea	low toxicity in sol. range		--	--	115	110
Omazene	copper dihydrazinium sulfate	--	--	0.83	0.83	--	--
Phygon XL	2, 3-dichloro 1, 4-naphthoquinone	0.08	0.07	--	--	not toxic to 0.042	
Simazine	2-chloro-4, 6-bis-(ethylamino)-s-triazine	--	--	7.0	6.6	--	--
Sodium TCA	sodium trichloroacetate	--	--	not toxic to 870 p. p. m.		--	--

Experiments involving constant flow of solutions of herbicides were conducted with aminotriazole, Dowpon, Simazine and Endothal. Chinook salmon were used as test animals in the Simazine experiment; in the other tests, largemouth bass were used. The constant flow apparatus operated by a gravity water flow through five-gallon pyrex bottles that were immersed in a water bath thermostatically controlled at 20° C. Intake water passed through a head jar that also contained a thermostatically controlled heater which adjusted the incoming water to 20° C. before it entered the test bottles. Outflow lines from each of the five test bottles could be manipulated vertically, thus controlling the amount of water that passed through each bottle. Solutions of herbicides were stored in 15-gallon pyrex bottles and pumped into the test containers at a uniform rate by means of a Brittingham laboratory pump (Setter et al., 1953). The amount of herbicide delivered was measured, and the water outflow was adjusted to obtain the desired concentrations in the test bottles. Outfall delivery from each dilution was calibrated every 24 hours during each experiment in order to maintain a uniform concentration.

RESULTS

ACP-M-569

This formulation contained aminotriazole and other undisclosed ingredients. Median tolerance limits were estimated for chinook salmon as follows: 24-hour, 185 p.p.m.; 48-hour, 155 p.p.m. At 370 p.p.m. 90 percent of the test animals died within 3 hours.

Aminotriazole

This herbicide failed to kill largemouth bass in 96-hour standing water bioassays at concentrations up to 1000 p.p.m., but in the constant flow apparatus 1000 p.p.m. killed all test fish in 6 days. Largemouth bass survived 62.5 p.p.m. for the 14-day duration of the constant flow test. The 24-hour median tolerance limit for coho salmon exposed to aminotriazole was 325 p.p.m. All mortalities in this experiment occurred within the first 24 hours, none in the ensuing 72 hours. Data supplied by the American Chemical Paint Company from tests conducted at the Academy of Natural Sciences of Philadelphia (1956) indicate that the toxicity of aminotriazole to bluegills is quite low, the 24-

hour median tolerance limit being 14,300 p.p.m. and the 48-hour TL_m 10,000 p.p.m. The summarization by Lawrence (1958) lists the concentration "safe" to fish as 1470 p.p.m.

Baron

The 24-hour median tolerance limit for chinook salmon was estimated to be 2.6 p.p.m. and the 48-hour TL_m 2.3 p.p.m. For largemouth bass the 24-hour TL_m was estimated to be 4.6 p.p.m. Lawrence (op. cit.) reports 5 p.p.m. as "safe" to fishes.

Dowpon

No mortalities resulted from exposure of largemouth bass to concentrations of dalapon up to 1000 p.p.m. in standing water, but in constant flow experiments no bass survived 48 hours exposure to 1000 p.p.m. Survival in 250 p.p.m. was complete over a period of seven days. Median tolerance limits for coho salmon were estimated as follows: 24- and 48-hour, 340 p.p.m.; 72-hour, 325 p.p.m.; 96-hour, 310 p.p.m. Lawrence (op. cit.) reports 3000 p.p.m. as being "safe" for fish.

Diquat (FB. 2)

The estimated median tolerance limits of chinook salmon for 24 and 48 hours were 29.5 p.p.m. and 28.5 p.p.m. respectively. At 100 p.p.m. all chinook salmon exposed died within 2 hours.

Mr. John S. Alabaster of the British Ministry of Agriculture has given permission to quote the following median tolerance limits for rainbow trout exposed to diquat at 18° C: 24-hour, 90 p.p.m.; 48-hour, 70 p.p.m.; 96-hour, 60 p.p.m.

Diquat evidenced toxicity to Ceratophyllum demersum and Elodea densa in laboratory screening tests at concentrations as low as 1 p.p.m.

Diuron (Karmex)

Largemouth bass were resistant to Diuron within the solubility range of the compound (42 p.p.m.). The 24- and 48-hour median tolerance limits for coho salmon were 33 and 16 p.p.m. Preliminary experiments indicated that bluegills were quite resistant in the laboratory whereas white crappies, Pomoxis annularis (Rafinesque),

were killed by concentrations as low as 6 p.p.m. Aeration slightly reduced the toxicity of Diuron.

Treatment of ponds with 5 and 10 p.p.m. Karmex resulted in the death of bluegills and largemouth bass. The 10 p.p.m. treatment apparently eradicated all fish and bullfrog tadpoles from the pond. Reduction of dissolved oxygen is thought to have contributed to the mortality.

Endothal

For chinook salmon the 24-hour TL_m was 155 p.p.m. and the 48-hour TL_m , 136 p.p.m. The 24-hour TL_m for largemouth bass was 200 p.p.m. No additional bass died after 24 hours. At 180 p.p.m. all chinook exposed died within 1 hour, and at 320 p.p.m. all bass exposed died within 2 hours.

In 96 hours of exposure in the constant flow apparatus, no largemouth bass mortalities were observed at 135 p.p.m. which was the highest concentration tested.

In experimental field studies, Endothal controlled Potamogeton pusillus at about 0.3 p.p.m. with no loss of largemouth bass or bluegills which were present in the pond.

Fenuron

Results of bioassays with this compound were extremely variable and no median tolerance limit was estimated. All coho salmon exposed to 56 p.p.m. survived for the 96-hour duration of the test, whereas 750 p.p.m. killed all test fish within 24 hours. Ten concentrations between the two mentioned above gave no consistent trend.

F-98 (Acrolein)

This compound proved to be quite toxic to salmonoid fish in jar bioassays. The 24-hour TL_m for chinook salmon at both 20°C. and 13°C. was near 0.08 p.p.m. For rainbow trout the 24-hour TL_m was near 0.065 p.p.m. At 1.35 p.p.m. all chinook were killed within two hours. In short-term exposures, 15 minutes exposure to 2 p.p.m. resulted in the death of all test fish within one hour of removal from the solution. Dr. Rene Blondeau of the Agricultural Research Division of the Shell Development Company reported in personal correspondence that during field work with acrolein fish showed severe agitation when they were exposed

to concentrations of from 10 to 15 p.p.m. Dr. Blondeau further stated that below 4 or 5 p.p.m. many fish seemed to escape after exposures of several hours. Carp and thread fin shad appeared quite sensitive to acrolein, whereas largemouth black bass seemed more resistant.

Applegate *et al.* (1957) report that no deaths occurred when rainbow trout, bluegill sunfish and sea lamprey were exposed to 5 p.p.m. acrolein for 24 hours.

Hyamine 1622

Estimated median tolerance limits for coho salmon were 57 p.p.m. and 53 p.p.m. for 24 and 48 hours. In laboratory screening experiments, this compound killed Elodea densa at 2 p.p.m.

Kuron

The 24- and 48-hour median tolerance limits estimated for chinook salmon were 1.35 p.p.m. and 1.23 p.p.m. respectively. The 24-hour TL_m estimated for largemouth bass was 3.5 p.p.m. In open plot experiments in Siltcoos Lake, Oregon bass fingerlings were killed by a concentration of about 5 p.p.m. A "safe" concentration of 3 p.p.m. is listed by Lawrence (*op. cit.*).

Monuron (Telvar, CMU)

This material was relatively non-toxic to largemouth bass within the solubility range (to 230 p.p.m.). Bass exposed to 135 p.p.m. and greater concentrations were narcotized but after 48 hours only 10 percent of those exposed to 230 p.p.m. were dead. Twenty-four and 48-hour median tolerance limits for coho salmon were 115 and 110 p.p.m. A preliminary experiment with bluegill, Lepomis macrochirus (Rafinesque), indicated that species has a tolerance similar to that of coho salmon. Aeration partially detoxified solutions of Monuron (Fryer 1957).

Treatment of two Willamette Valley ponds with 5 and 10 p.p.m. Monuron apparently caused no mortality of frogs, tadpoles or fishes. Rudd and Gennelly (1956) cite an instance of fish mortality with 4.6 p.p.m. "CMU". A report from the E.I. DuPont de Nemours Company (1954) indicates that several warm water fish species could withstand 40 p.p.m. Monuron for 10 days.

Lawrence (op. cit.) lists a "safe" concentration of less than 1.2 p.p.m. for "CMU".

Omazene

Concentrations of 1.8 p.p.m. and above killed all chinook salmon in 48-hour exposure.

Phygon XL

Much difficulty was experienced in working with this formulation, as it appeared to lose its toxicity rapidly. No reliable estimation of its toxicity to coho salmon could be made, although Phygon XL caused no mortality at 0.042 p.p.m. and lower concentrations.

The 24-hour TL_m for largemouth bass was estimated to be 0.08 p.p.m. and the 48-hour TL_m , 0.07 p.p.m.

Fitzgerald and Skoog (1954) report treatment of a lake with up to .055 p.p.m. Phygon XL with no fish mortality. O'Brien (1956) mentions cases in which Phygon XL has proven toxic to fish. A "safe" concentration range of 0.05 to 0.6 is given by Lawrence (op. cit.).

Simazine

The tolerance of chinook salmon to Simazine was determined in both standing water and constant flow experiments. Somewhat contradictory results were obtained for the first 24 hours of exposure. In standing water, a 24-hour TL_m of 7.0 p.p.m. was estimated while in the constant flow device all test fish survived 24-hour exposure at 10 p.p.m. The estimated 48-hour TL_m in standing water was 6.6 p.p.m. while that for the constant flow experiment was 7.7

p.p.m. Median tolerance limits for 72 and 96 hours estimated from the constant flow experiment were 7.2 p.p.m. and 6.5 p.p.m. respectively. We have no explanation available for the discrepancy at this time.

Sodium trichloroacetate

No mortalities of chinook salmon were sustained during 48-hour exposure to concentrations ranging up to 870 p.p.m.

Short-period exposures

No mortalities occurred in coho salmon for 24 hours following 15 and 30-minute exposures to 5 and 10 p.p.m. arsenic trioxide, 5 p.p.m. Baron, 5 and 10 p.p.m. Kuron, 0.5 and 1.0 p.p.m. Delrad, 0.1 p.p.m. Phygon XL, 1 and 2 p.p.m. copper sulfate or 50 p.p.m. trichlorobenzene with 5 percent Colloidal X-77 emulsifier. Thirty minutes exposure to 10 p.p.m. Baron killed 10 percent of the test animals within one hour of removal from the solution, whereas 15 minutes exposure to that concentration killed no fish. Exposure to 0.5 p.p.m. Phygon XL for 15 minutes resulted in 20 percent mortality by the end of one hour, and 60 percent mortality within 24 hours of removal from the solution. Thirty minutes exposure to 0.5 p.p.m. Phygon XL produced 80 percent mortality within 1 hour and 100 percent mortality within 3 hours of removal from the solution. After 30 minutes exposure to 100 p.p.m. emulsified trichlorobenzene, 20 percent of the test fish died within 12 hours. Fifteen minutes exposure to 100 p.p.m. caused no deaths within 24 hours. All test fish exposed to 2 and 4 p.p.m. acrolein were dead within one hour after their removal from the solutions.

REFERENCES

Academy of Natural Sciences of Philadelphia. 1956. Toxicity of 3-amino-1, 2, 4-triazole to *Lepomis macrochirus* for the American Chemical Paint Company. 7 numbered leaves (mimeographed).

Applegate, Vernon C. et al. 1957. The toxicity of 4,346 chemicals to larval lampreys and fishes. U. S. Dept. of Interior, Fish and Wildlife Service, Special Scientific Report--Fisheries--207. 157 p.

Doudoroff, P. et al. 1951. Bioassay methods for the evaluation of acute toxicity of industrial wastes to fish. Sewage and Industrial Wastes 23:1380-1397.

E. I. DuPont de Nemours and Company, Inc. 1954. Toxicity of 3-(p-chlorophenyl)-1, 1-dimethylurea and 3-(3, 4-dichlorophenyl)-1, 1-dimethylurea. Wilmington, Delaware. 4 p. (mimeographed).

Fitzgerald, G. E. and Foke Skoog. 1954. Control of blue-green algae blooms with 2, 3-dichloronaphthoquinone. Sewage and Industrial Wastes 26(9):1136-1140.

Fryer, John L. 1957. Toxicity of some new herbicides to fish. Master's Thesis. Oregon State College. 50 numbered leaves.

Lawrence, J. M. 1958. Methods for controlling aquatic

weeds in fish ponds with emphasis on use of chemicals. Agricultural Experiment Station, Alabama Polytechnic Institute, Progress Report series No. 69, 4 p. 1 chart.

Lewis, Robert H. 1959. Effects of selected aquatic herbicides on fishes. Master's Thesis. Oregon State College. 81 numbered leaves.

O'Brien, G. E. 1956. Dichlone as a control for algae and submerged aquatic weeds. Bethany Information Sheet No.

82. U. S. Rubber, Naugatuck Chemical Division. 5 p.

Rudd, R. L. and R. E. Genelly. 1956. Pesticides: their use and toxicity in relation to wildlife. California Department of Fish and Game. Game Bulletin No. 7. 209 p.

Setter, L. R., W. E. Brittingham and R. F. Wessels. 1953. The Brittingham laboratory pump. Sewage and Industrial Wastes 25(7):798-801.

PANEL SUMMARY

Clarence Cottam, Director, Welder Wildlife Foundation, Sinton, Texas^{1/}

It is to be noted that at this Second Seminar on Biological Problems in Water Pollution more than 300 biologists from a considerable number of disciplines, backgrounds, training and experience have been in session for the past five days and nights. As evidence of the breadth and importance of the program and of its widespread and timely appeal, it may be recorded that scientists, with a few administrators, were in attendance from 44 or more states, including Alaska, plus the District of Columbia, 6 Canadian Provinces, and one research worker each from the Philippines and Indonesia. Some 44% of those present were from universities and colleges, 30% from state departments of government (mainly state departments of health and conservation). The rest were from Federal bureaus (particularly research workers in the field of pollution), private industry, and private research workers and foundations. While the meetings have been open to the interested public, probably half of the 300 or more present were specifically invited or requested to attend.

These scientists and planners have been diligently considering a variety of facets and problems pertaining to water conservation, purification, pollution and public water supply. Five major sessions or panels have been held; two of these have been all day discussions. During this time, some 36 more or less formal papers have been given reporting findings and procedures and from these we have gained much pertinent and important information. Many stimulating questions, answers, and discussions have been offered by experienced workers commenting from the floor.

Perhaps equally as important as were the formal papers were some 12-15 different and lively, but informal, evening sessions that have been held discussing techniques and the more technical or specialized aspects of water pollution, testing, and water quality studies. Bio-assay procedures and techniques and fish

species and food chain organisms were discussed as they relate to the pollution problem.

Twelve papers were presented on the controversial but timely and important panel discussions dealing with the effects of pesticides on aquatic life. The paper by Cottam dealt with the overall effect of pesticides. He emphasized that these pesticides generally were highly toxic, wide spectrum, non-specific, and with long residual effects. The new poisons are surprisingly stable and their lethal qualities may last for many years. Consequently, most of them are extremely dangerous to man, his domestic animals, and they are devastating to our fisheries and wildlife. The urgent need is for less toxic and less stable poisons with a high degree of specificity and shorter life span. The use of these poisons is rapidly increasing and a fourfold increase is expected in another ten or fifteen years. Last year, about one-billion pounds of chemical pesticides were applied to about 100,000,000 acres of land.

The alarming magnitude of the problem and dangers to human health points to the urgent need for much closer cooperative work between control workers and agencies (mainly governmental) and those whose interests are affected. Control workers should have better grounding in ecology, so as to appreciate the indirect and long-term, as well as the direct effects of control operations.

The paper by Byrd, as well as the one by Cottam, was understandably critical of the ill conceived, immature, and irresponsible fire ant "eradication" program, directed by control workers of the Department of Agriculture. This misdirected operation is doing serious and unnecessary damage to fish and wildlife resources in the nine states where it has been in operation the past two years. Highly lethal poisons have been put out in too many areas where few or no fire ants occur. The facts indicate that misin-

^{1/}Contribution No. 37, Series A, Welder Wildlife Foundation

formation on the damage by fire ants has been given out. It is not a serious economic destroyer of agriculture, livestock or wildlife but a nuisance and pest that deserves local but effective control.

Professor Carl Bond pointed out the considerable increase in numbers and quantities of herbicidal materials being used for both terrestrial and aquatic weed, brush, and tree control. Many of these poisons, and particularly the chlorinated hydrocarbons and aromatic solvents, are highly toxic to fish and food chain organisms. Acrolein and herbicides containing carbon and esters of Silvex were extremely toxic, while some of the new compounds being tested showed only moderate toxicity. Better methods for bridging the gap between laboratory and practical field testing are needed.

Dr. O. B. Cope pointed out that DDT is commonly stored in tissues of birds and mammals and in the fatty tissues of most humans in this country. By chemical analysis, he also found DDT in trout tissue, and the greatest concentration was in the body fat. Kidneys held the second highest amount with the pyloric caecum and the brain containing smaller amounts. The fish liver contained no DDT. Whitefish contained more DDT and DDE than did species of trout. Fish taken 85 miles downstream from a sprayed area showed DDT, and fish contained DDT at all seasons and for at least 11 months after spraying. DDT was also found in all "control" fish, even from untreated streams, fish hatcheries, and fish markets. The source of this poison in these fish is unknown.

It was the conclusion of Dr. Hoffman that much of the fish and wildlife losses attributed to insecticides may be due to misuse and cleaning of spray equipment in ponds and streams. He felt that most large-scale spray operations were skillfully directed by state and federal authorities, so that most losses were negligible and temporary. The public should be fully advised well in advance of the needs, procedures, and hazards of a proposed control operation. Close, friendly, and helpful cooperation of all interests is a necessity. Research on biological control is underway and must continue and include cultural practices. More specific and less wide-spectrum insecticides are needed. Dr. Hoffman reported on the very successful control of screwworms in the Southeast through the sterilization of the males with gamma rays from cobalt

60. Much study is needed to apply this treatment to the destructive screwworms of the Southwest. There was full agreement with the conclusion that with the wide expanding use of insecticides there needs to be detailed cooperative studies between entomologists, fish and wildlife biologists, chemists and others concerned. Some of the new carbamate and organic phosphorus insecticides seem to be much less damaging to wildlife interests. Field studies need to be accelerated in the broad insecticide program.

Professor Graham (as presented by R. C. Thomas) found fish dying in the Yellowstone River 90 miles below the treated watershed where 300,000 acres were sprayed with DDT in 1955 and 800,000 acres in 1957. Four months after spraying, fish (mainly whitefish, brown trout, and suckers) were dying in the river and 600 dead or dying fish were noted in less than 300 yards of the stream. DDT was found in these fish. Spraying had been at the rate of one pound of insecticide oil emulsion per acre. Bottom organisms in one tributary had reached prespray quantities by the end of the second summer after spraying, but were still below this level in five other streams. Still another stream had shown only slight recovery by that time. Some early summer, 1957, spraying showed no appreciable loss, except with suckers, until November and December. This delayed mortality was most severe with the fall spawners, brown and brook trout and whitefish. The sucker mortality occurred just after spawning. Loss of the four species occurred when the fish were in poor condition and under physiological stress. This suggests that the stored DDT then becomes lethal. Professor Graham expressed grave doubt as to the wisdom and effectiveness of the control program.

In Dr. F. E. Webb's discussion of aerial forest spraying in Canada, in relation to aquatic life, he stressed the advisability of a conservative approach in the use of pesticides and also the necessity of sound cultural methods to aid control. In the control program he felt that the biologist's task is: (1) to foster the idea that the problems of pest control are primarily ecological and, (2) to insure the safest and most intelligent use of direct control measures. Some serious damage to the young salmon runs in New Brunswick are believed to have occurred and it is anticipated that the maximum effects will likely be most in evidence in 1961. Research

is needed to find less damaging insecticides to fish and wildlife when necessity demands control of forest insect pests.

J. B. Sprague reported that the Fisheries Research Board of Canada was conducting population dynamics studies of salmon in New Brunswick when the forests were sprayed (as reported by Dr. Webb). Spraying in 1954 virtually eliminated salmon fry and killed most parr. Numbers of fish were also reduced during 1956 and 1957, in portions of the watershed sprayed. There were indications of unfavorable changes in growth rates in the years following spray operations. This was undoubtedly due to the destruction of food chain organisms.

In the control of aquatic forms, Dr. V. L. Loosanoff of the Milford, Connecticut Laboratory reported that DDT on oyster collectors (shells, etc.) would prevent setting of barnacles. Other insecticides are useful in controlling aquatic pests which are either competitors or enemies of commercially important shellfish. Guthion, Dipterex, Lindane, TEPP, Sevin, Dieldrin and others are of value as aquatic pest controls. Some 3,000 organic compounds were tested. Any chemical to be used must be thoroughly evaluated by experienced biologists to determine procedures of control in a given area. If wisely handled they can control the pests without significant adverse effects upon the commercial shellfish.

Perhaps one of our best and most encouraging examples of a chemical used as a specific control agent is the compound used against the larvae of the lamprey in the Great Lakes, as reported by Dr. Vernon C. Applegate of the Fish and Wildlife Service. This aquatic pesticide was successfully used and apparently without doing measurable injury to the fish or their food chain. The compound is the recent discovery of a sodium salt used under the trade name of Lamprecid 2770, a sodium salt of 3-trifluoromethyl-4-nitrophenol. Lamprecid 2770 was applied to the river for nine hours and a total of 45 1/2 gallons (385 lbs.) of the formulation were used.

From bioassay and chemical studies Crosswell Henderson of the Taft Sanitary Engineering Center showed that a number of the new pesticides are exceedingly toxic to fish. There was an extremely wide range in the toxicity of the different compounds as indicated by 96 hour

TL_m values. Several of these compounds were far more toxic to bluegills than to fathead minnows. The organic phosphorus compounds tested were EPN, Para-oxon, Parathion, TEPP, Chlorothion, Systox, Methyl Parathion, Malathion, Dipterex, OMPA, Guthion, Di-syston and Co-ral. Their toxicity as indicated by the 96 hour TL_m value ranged from 0.005 to 121 ppm.

The chlorinated hydrocarbons (Endrin, Toxaphene, Dieldrin, Aldrin, DDT, Methoxychlor, Heptachlor, Lindane, Chlordane, and BHC) were generally more toxic than the organic phosphorus compounds. All of these compounds except BHC were extremely toxic to fish with 96 hour TL_m values generally below 0.1 ppm. Endrin was the most toxic with TL_m values ranging below 0.0005 ppm. Besides their exceedingly high toxicity, their residual effects are amazingly long lasting, which makes them doubly dangerous.

Bioassays with the new carbamate, Sevin, indicates a low degree of toxicity to fish (TL_m 5.5 to 13 ppm). For most compounds tested, water quality had little effect on toxicity. Henderson appropriately concluded that "the most promising approach to the solution of the insecticide problem, with respect to fish, appears to be the development of selective insecticides that are relatively non-toxic to fish or the addition of antagonistic agents for the reduction of toxicity".

The Public Health Service Toxicologist, Dr. Herbert E. Stokinger pointed out some of the many toxicological problems associated with the use of economic poisons. In 1957-1958, California alone had nearly 400 cases of pesticide poisoning, representing 1% of all accidents. Toxicity problems must be considered and balanced between beneficial and harmful effects of using a particular compound in control. We must know the toxicity and the hazards of the control agent. The following major groups of control agents are now in common use: 36 insecticides; 20 herbicides and brush killers; 30 fungicides; 9 miticides; 9 rodenticides; 10 soil sterilants and defoliants; 15 space and soil fumigants; 3 piscicides; 30 insect repellents and 10 plant-growth regulators and a considerable number of rodent and other mammalian repellents.

Before these groups of chemical compounds were given clearance, their permissible tolerances were established by the Federal Food and

Drug Administration. Extensive toxicological investigations were conducted. For general use a pesticide must have passed the requirements of F.D.A. Dr. Stokinger pointed out that the toxicity of a substance was a competition between the toxic agent on the body and the chemical action of the body on the toxic agent. Almost invariably, organic compounds are modified chemically by the body.

The subject matter treated by this eminent group of experts was stimulating, thought provoking, and rewarding, indeed. Not the least value of a conference of this sort is the oppor-

tunity to rub shoulders, to exchange views, and to meet eminent leaders in many related disciplines. The influence of this meeting will assuredly serve as a leaven to raise the standard of biological work throughout our continent. The Public Health Service, The Taft Center, Director Hanson and his staff, and particularly Dr. Clarence Tarzwell, deserve our thanks for bringing this group together. The program had been thoughtfully prepared and the meetings under Dr. Tarzwell generally have been skillfully handled. We compliment the leadership at this Center. This, in my opinion, has been an eminently successful conference.

THE OXYGEN REQUIREMENTS OF FISH

F. E. J. Fry - Department of Zoology, University of Toronto and Division of Research
Ontario Department of Lands and Forests

There are three levels of oxygen requirement that may be considered for aerobic organisms such as fish. These are: (1) the level that just permits the animal to exist, the incipient lethal level; (2) the level that permits it to be active to a given specified degree; and (3) the level that will permit it to remain in a given locality. Each of these levels is of significance under a particular circumstance.

The minimum level for existence may be the standard permissible for relatively short periods, say briefly during the diurnal cycle, in ponds or such bodies of water which the fish cannot vacate. In running water, and in all waters except for brief periods, the oxygen standard set must meet a requirement that is well above the minimum for existence. Otherwise the fish will not be able to grow or to carry on the activities necessary for their continued existence. Finally, a level of oxygen that will permit a certain minimum degree of activity may not be sufficient to maintain a population in a given locality, because at that level the fish are restless with the result that their continued movement takes them away from there. This latter phenomenon, however, has not yet been well investigated.

The incipient lethal level that is to be understood here is the minimum level of oxygen at which the continued existence of the individual is just possible. It may be determined by experiment directly or it may be inferred from measurements of respiration as is outlined in the section next following. Direct determinations of the lethal level should be made in running water. Otherwise the uptake by the fish while in a dying state will continue to reduce the oxygen content of the water below that which will actually support its life on a continuing basis. Shepard (1955) gives a clear discussion of this point as well as describing apparatus for the reduction of the oxygen in water and the general conduct of tests to determine the lethal level of

oxygen. The divergence between the curves labelled "asphyxial" and "residual" in Figure 3 show the extent of the error that may be entailed if closed instead of open systems are used in determining the lethal level.

The indirect method of determining the tolerance level of low oxygen is to determine the rate of oxygen consumption of the fish under two conditions, when it is undisturbed after resting for some time (standard metabolism) and while it is stimulated to continuous activity (active metabolism). A general outline of this method is given in Brown (1957), chapter 1, and a detailed example of its application is provided by Job (1955). The most recent description of the method for determining the respiration of fish under activity is that of Basu (1959). A different variant of the rotating chamber method is described by Wohlschlag (1957). The respiration of the active fish is determined over a series of concentrations of dissolved oxygen, that of the quiet fish usually at a single level near air saturation.

The two series of measurements of respiration can be combined as is shown in Figure 1. Here the two upper curves show typical relations between the consumption of oxygen by active fish and the oxygen concentration. They also show the typical effect of temperature on oxygen consumption. The lowermost and horizontal line passes through the determination of the standard metabolism at 10°C., the corresponding active line being the lower of the two curves for active metabolism. The oxygen concentration at the intersection of the two curves describing active and standard metabolism may be taken as that at which the fish can just continue to exist with a minimum of external activity, and has therefore been termed "the level of no excess activity". The level of no excess activity can be taken as a conservative estimate of the incipient level. It will ordinarily be slightly higher than the lethal as

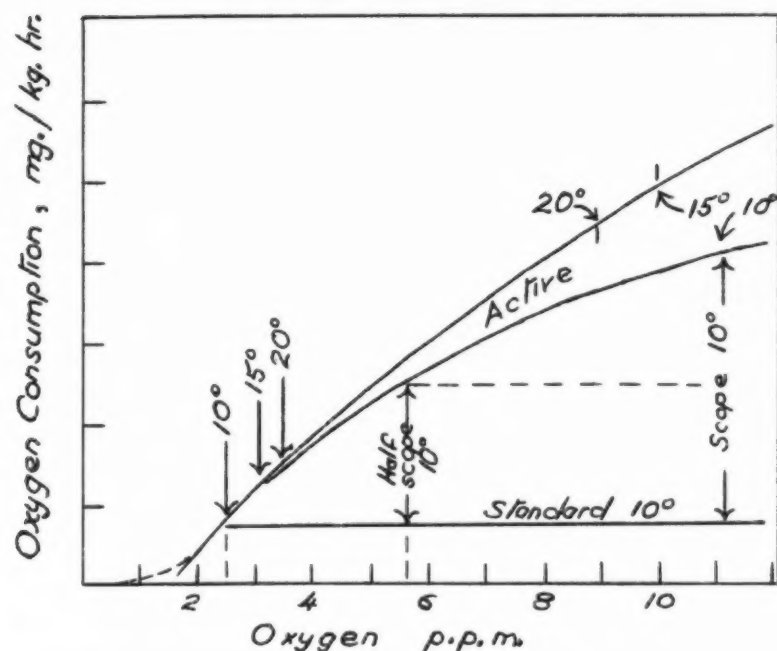


Figure 1. The respiration of the speckled trout in relation to temperature and oxygen content. From Data of Basu (1959) and Job (1955). Calculated for fish weighing approximately 170 g. The vertical arrows represent the levels of no excess activity for 15° and 20° C. respectively, which are not discussed in the text.

determined by direct experiment because the standard metabolism usually includes some oxygen consumption arising from slight spontaneous activity.

The advantage of making an estimate of the incipient lethal level by the indirect means of measuring the active and standard metabolism is that the same two curves can also be used to estimate a more realistic minimum for the oxygen requirements of fish. The incipient lethal level, of course, is not a standard that can be accepted for any but the briefest and most unusual emergency.

Where the curve representing the active oxygen consumption levels off, the fish may be said to have its full scope for aerobic activity. Quantitatively, the scope for activity may be expressed as the difference between the two lines for standard and active metabolism, the scope being zero of course at the level of no excess activity. If attention is given to Figure 1 it will be seen that the active rate of metabolism varies with the concentration of oxygen over a wide range, even up to air saturation in the species shown. The curves given are for

the speckled trout which is well known to require well-aerated water, but essentially the same type of curve is found for the carp also (Basu, 1959). Apparently if it is to be fully active, a very active fish requires water that is essentially air-saturated regardless of whether the species may be sensitive or tolerant to oxygen as measured by the lethal level.

Since so many species probably require full air saturation or more for their full scope it would be unrealistic to require a minimum standard of oxygen concentration in waters receiving wastes that would permit the full scope of all species. The standard that has been suggested (e.g. Basu, 1959) is the half scope, meaning half the scope at air saturation. In Figure 1 the half scope for the speckled trout at 10°C. is shown to lie at approximately 6 p.p.m.

The chief uncertainty in this method of setting a standard for oxygen concentration lies in the determination of the point where the fish achieves its full scope, unless that point is beyond air saturation. It is necessary to design an experiment in which the fish is stimulated to maximum continuous activity. Basu (1959) discusses this point. The suggestion of the half-scope level as the minimum standard is an arbitrary and to a certain extent tentative suggestion. However the principle by which the half scope is determined can be used to estimate the requirements for any other fraction of the scope for activity that future experience may suggest as a more valid standard.

The level of oxygen at which fish become restless apparently has not been given a name, nor has this response to oxygen been subject to the same degree of analysis as have the levels relating to the needs of fish for existence and activity. The point where fish are stimulated to move by decreased oxygen might be termed the "oxykinetic level" following the classification of Fraenkel and Gunn (1940). The pioneering work on movement of fish in relation to oxygen concentration was done by Shelford and Allee (1913) but the most complete investigations to date have been those of Jones (1952), who also developed somewhat more effective apparatus for the purpose. Jones' experiment was to place the fish in a large bore glass tube with a water supply at either end and a drain in the middle. Water with a chosen level of oxygen is introduced at one end of the tube while air-saturated water is introduced at the other. Both

streams of water are previously led through a heat exchanger so that they have attained the same temperature. The effect on the fish is then observed and may be measured by the time required for the fish to vacate the sector of the tube in which the oxygen is low. Although there are few data to support the belief, it appears probable that the oxykinetic level would be somewhat below the half-scope level but somewhat above the level of no excess activity.

It is highly probable that none of these levels of oxygen requirement can be considered independently of other environmental factors, nor indeed from the mere effect of the size of the fish itself. In assessing the effects of such interactions, the indirect method of estimating them from the respiration curves offers much economy of effort. The effect of size on the level of no excess activity in relation to temperature is well demonstrated in this way for the speckled trout by Job (1955). He found that the slope of the line relating active metabolism to size was less than that for standard metabolism at higher temperatures. In consequence the level at 20°C., of no excess activity was higher for large fish than for small ones. The reverse held true at 5°C.

A method for estimating the interaction between carbon dioxide and oxygen in their effects on respiration has been developed by Basu (1959). The procedure is to measure the active respiration rate at a series of combinations of oxygen and carbon dioxide, getting a series of curves of the type shown in Figure 2. The data in Figure 2 can be combined with the observations graphed in Figure 1 to give estimates of the respiratory sensitivity of fish such as are shown in Figure 3. The two levels of oxygen consumption (derived from Figure 1) indicated by the horizontal broken lines in Figure 2 provide the data for determining the two upper curves in panel A of Figure 3. For example, to determine the half-scope curve (the uppermost curve in the panel), it will be seen that the half-scope rate is satisfied when the oxygen is at air saturation until the concentration of carbon dioxide reaches 28 p.p.m., as is indicated by the intersection of the half-scope line and the line representing the active rate of oxygen consumption when oxygen is at air saturation and carbon dioxide is varied. Similarly, as the intersection of the half scope line with the 75% line shows, the half-scope rate can be met by the fish at concentrations of carbon dioxide no

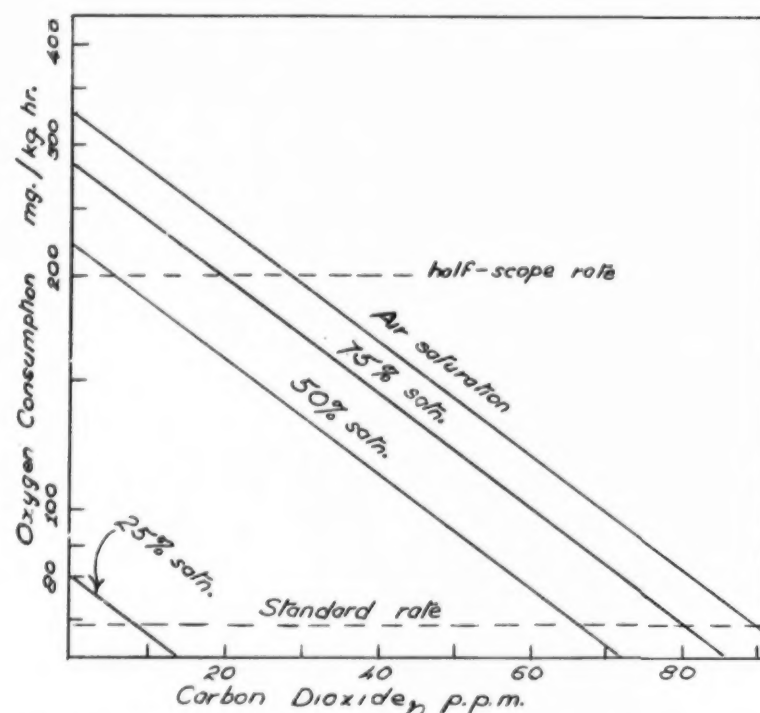


Figure 2. The combined effect of oxygen and carbon dioxide on the respiration of the speckled trout at 10°C. Calculated from the formula given in Basu (1959), Table 4. Fish of same weight as those represented in Figure 1.

higher than 20 p.p.m. if the oxygen concentration in the water is no more than 75% air saturation. Below 50% saturation at 10°C. no appreciable carbon dioxide can be tolerated if the fish is to meet its half-scope requirements, nor can the oxygen content drop much below 50% for this standard to be met even in the absence of carbon dioxide.

In a similar fashion, the second curve showing the limits beyond which the requirements even for the level of no excess activity for the speckled trout cannot be met, can be found from the intersects of the lower hatched line in Figure 2 with the four respiration curves plotted.

It will be noted that the active respiration curves plotted in Figure 2 are parallel straight lines. Basu's investigations of four species indicates that such a response is likely to occur down to quite low levels of oxygen (about 10% air saturation). Accordingly it appears that, having found the basic data illustrated in Figure 1 only one series of further experiments is necessary at any given temperature, in which oxygen is held constant and carbon dioxide varied, to provide all the data required to make such estimates as are given in Figure 3. More-

over such indirect estimates can doubtless be made for combinations of other factors with oxygen, but none appear to be yet available.

In conclusion it would appear that the best single standard for the oxygen requirements of fish would be some measure similar to the half-scope level. The incipient lethal level is in general far too low a level to be an acceptable

standard. Moreover such lethal levels as have been determined have often been obtained by methods which have made them serious underestimates of the actual requirements even for the mere support of life. The phenomenon of oxykinesis has been rarely investigated and further work on this subject is needed to assess its relative importance.

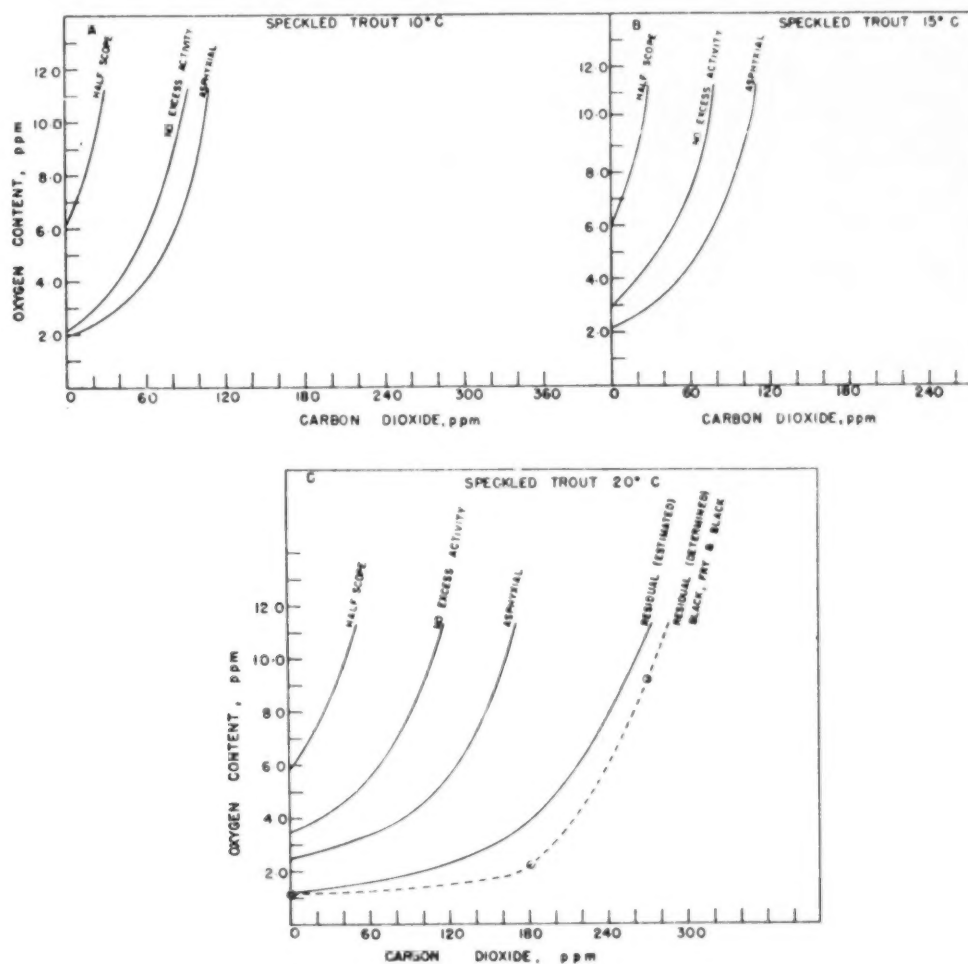


Figure 3. Various tolerance limits of combinations of oxygen and carbon dioxide for the speckled trout. Reproduced from Basu (1959), Figure 12. Based on fish of the same size as those represented in Figures 1 and 2.

REFERENCES

- Basu, S. P. 1959. Active respiration of fish in relation to ambient concentrations of oxygen and carbon dioxide. *J. Fish. Res. Bd. Canada*, 16:175-212.
- Black, E. C., F. E. J. Fry and V. S. Black. 1954. The influence of carbon dioxide on the utilization of oxygen by some fresh-water fish. *Can. J. Zool.*, 32:408-420.
- Brown, M. E. (Ed.). 1957. *The Physiology of Fishes*. 2 vols., New York, Academic Press.
- Fraenkel, G. S. and D. L. Gunn. 1940. *The Orientation of Animals*. Oxford Univ. Press.
- Job, S. V. 1955. The Oxygen Consumption of *Salvelinus fontinalis*. *Univ. Toronto Stud., Biol. Ser.* 61, Pub. Ont. Fish. Res. Lab., 73:39 pp.
- Jones, J. Erichsen. 1952. The Reactions of Fish to Water of Low Oxygen Content. *J. Exp. Biol.*, 29:403-415.
- Shelford, V. E. and W. C. Allee. 1913. Reactions of Fishes to Gradients of Dissolved Atmospheric Gases. *J. Exp. Zool.*, 14:207-266.
- Shepard, M. P. 1955. Resistance and Tolerance of Young Speckled Trout (*Salvelinus fontinalis*) to Oxygen Lack, with Special Reference to Low Oxygen Acclimation. *J. Fish. Res. Bd. Canada*, 12:387-446.
- Wohlschlag, D. E. 1957. Differences in Metabolic Rates of Migratory and Freshwater Forms of an Arctic Whitefish. *Ecology*, 38:502-510.

THERMAL REQUIREMENTS OF FISH—THREE DECADES OF STUDY, 1940-1970

J. R. Brett - Fisheries Research Board of Canada, Biological Station
Nanaimo, British Columbia

ABSTRACT

Three decades of research (1940 to 1970) on temperature relations in fish, and cold-blooded animals generally, are discussed. Speculation on the trends in the next decade are made from a survey of current literature.

Temperature acts in a variety of ways. It may kill, reduce activity, interact with other environmental factors, confine reproduction, and be a directing agent where a gradient exists.

Differences between species in maximum temperature tolerance can be as great as 17°C. (31°F.), and, in overall tolerance, a difference factor of 2.7 times can separate the most tolerant from the least tolerant. Despite ability to withstand low temperatures, slow rates of acclimation appear to result in greater mortalities from cold in nature.

Temperature controls the activities of fish by regulating rates of metabolism (resting and active). The numbing effects of low temperature restricting performance, or the equally restricting effects of high temperature demanding excessive body maintenance are of serious consequence for maintaining continuity of a species. Research on this aspect and the information made available is required if adequate thermal relations are to be prescribed for fish: In order to prescribe thermal requirements, limits to the "safe" reduction of activity imposed by temperature are set forth as a basis for discussion.

Research on the interaction and stress from environmental factors, employing long-term observations, at all stages of development can be expected to reach a new level in the next decade.

INTRODUCTION

Within the general bounds of the last two decades (1940-1959) it has been possible, in retrospect, to see many of the "seeds of thought" for research in temperature relations taking root in the one or two years preceding each decade. Although there is quite a vast literature dating back into the last century which could conceivably bear on the subject of thermal requirements in fish, the research was not tempered in the later knowledge of the considerable effects of temperature acclimation and the consequences of pre-history generally.

Prior to 1940 a great deal of the temperature work was of segmental significance, and difficult to draw into any generalized pattern. Categorically, it was known that upper and lower lethal levels existed, that acclimatization was a recognized phenomenon, that tolerance differences between species were apparent, and that if differences between internal body temperature and external environmental temperature did exist, these were slight and likely to be no more than transitory (see review by Brett, 1956). Early in the 1940's, and immediately preceding

this period, more systematic examination of temperature tolerance relations had commenced, particularly in the school of research headed by Fry (Fry et al., 1942) and in the association of Doudoroff working with Sumner (Sumner and Doudoroff, 1938; Doudoroff, 1942).

Thus, in the decade of the 1940's, although diverse experiments were underway, the emphasis of research in North America was on the extremes of temperature which could be endured and the precise modification of these induced by previous periods of thermal acclimation.

Prior to the close of this decade, Fry (1947) published a broader concept of temperature as an environmental factor, emphasizing the multiple role of temperature and categorizing its action in terms of lethal, controlling (governing metabolic rate), directive (gradient response) and accessory factors. This interpretation provided clarity to the paths of thinking which had been expressed in the literature, and set the scene for approaching thermal requirements through the medium of metabolism and temperature-dependent activities, a pattern of research which has been pursued with intensity in

the 1950's. Indeed, among poikilotherms in general there has been an impressive surge in the study of rate-temperature (RT) phenomena (Bullock, 1955).

Now, with the close of the 1950 decade, and accepting the momentum which tolerance studies and research on temperature-dependent activities undoubtedly carry into the next decade, it is interesting to speculate on the possible trends which will find new accent emerging in the 1960's. Under appropriate subsequent headings, brief summaries of the significance of the past two decades and anticipations in the next are set forth.

Before proceeding with this discussion, some consideration must be given to what is meant by "thermal requirements". The thought behind "requirements" is that of necessity rather than desirability or the maintenance of ideal conditions. It implies setting limits to what must be provided for the organism to permit survival at a level which allows for continuity of the species. Further, at any one time, it must be asked, thermal requirements for what? - for immediate survival, for good growth, for migration, for escape from predation, for successful osmoregulation, for spawning, or what? These are all activities or functions of one sort or another, some required throughout the life cycle, others imposing a requirement at specific times only.

It can be stated that a major requirement for a physical environmental factor like temperature is that it should provide for a level of activity commensurate with maintaining the species at a population level which is more than just a token sample. The particular range of temperature to meet this provision is not fixed, but is dependent on, or at least influenced by, such factors as season, diet, age and size, from egg to mature adult. It must allow for all those activities which relate to maintenance, food procurement and adequate digestion, not at an optimum level, but, to repeat, at a level commensurate with species survival. It is obvious that there can be no simple pronouncement on thermal requirements.

PHASES OF RESEARCH

Temperature—a lethal factor (the 1940 decade)

For any species it is desirable to know just what it can tolerate when faced with the problem of temperature as a lethal factor, acting directly on protoplasmic organization. This outer

framework, provided by the zone of tolerance (Figure 1), defines the final boundary between life and death. As recorded in the laboratory, in its upper and lower limits over a complete range of thermal acclimations, the end-points usually used are the median tolerance levels for exposures of time which indicate that mortality from temperature as a primary factor has ceased. It must be recognized that these boundaries do not reveal what can be resisted for shorter intervals, or at the other end of the time-scale, what detrimental long-term effects can accrue from secondary involvements. The lethal temperature then, is a sensitive, useful physiologic end-point when employed in its intended manner.

It is not the intention here to amass the numerous and growing records of tolerance which now exist among a wide variety of species. For this the compilation by Hart (1947), the review by Brett (1956), such texts as Heilbrunn's (1948), and the Handbook of Biological Data edited by

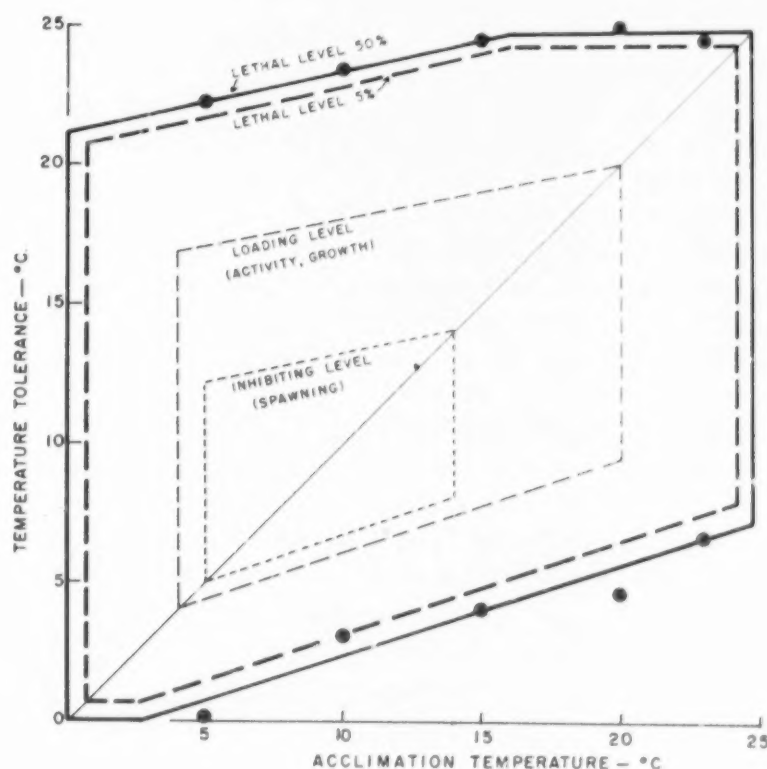


Figure 1. Upper and lower lethal temperatures for young sockeye salmon plotted to show the zone of tolerance. Within this zone two other zones are represented to illustrate (1) an area beyond which growth would be poor to none-at-all, under the influence of the loading effect of metabolic demand, and (2) an area beyond which temperature is likely to inhibit normal reproduction. (From Brett, 1958).

Spector (1956) are useful. A few pertinent points should be made, however.

All species to date, endemic to the United States and Canada, given adequate acclimation, have shown the ability to tolerate temperatures in the region of the freezing point of fresh water.* Rapidly onsetting low temperature, however, can constitute one of the greatest threats to survival when fish are accustomed to relatively warm water because of the inherent slow rate of acclimation to low temperature. There is, therefore, a required time-factor for acclimation which shows marked difference in duration within any given species depending on whether the temperature is rising or falling (Doudoroff, 1942; Brett, 1946).

The ultimate upper lethal levels can differ between species by as much as 17°C (31°F), e.g., *Carassius auratus* - 41°C (106°F), *Oncorhynchus gorbuscha* - 24°C (75°F), and the zones of thermal tolerance (as defined by Fry et al., 1942) by a factor of 2.7 times. Such differences demonstrate the very large variation in tolerance that exists, and the quite remarkable extremes which some species can withstand. In recent years, Bailey (1955) has recorded an interesting series of observations on heat-death in a mixed population of fish in a shallow bay in southern Michigan where the temperature rose to 38°C (100.4°F). Such instances of death from upper lethal temperatures are unusual. In nature species are usually found living well within their range of thermal tolerance.

Temperature -- a controlling factor (the 1950 decade)

The penetrating observation made by Fry in 1947 that temperature acts through metabolism on activity opened up a new approach to what was a somewhat dispersed not to say confused field of enquiry. Although there is a lot to be learned by studying the change in rate of any activity at a variety of temperature levels, the understanding and hence interpretation remains obscure without the knowledge of metabolic demand. By demonstrating that the performance or scope for activity was related to the difference between resting metabolism and active

metabolism, a means of examining the influence of temperature as a controlling factor was provided. Temperature, then, influences activity by governing the relative rates of energy demand for maintenance, and energy demand for performing essential work (e.g., swimming, digesting, courting, etc.). Since the characteristic feature of a controlling factor is to be operative at all levels, the animal never escapes the assets or liabilities imposed. A striking example of this relation can be taken from recent work on temperature and cruising speeds of young salmon, Figure 2 (Brett et al., 1958). For sockeye the maximum sustained swimming speeds at 10°C (50°F) and 19°C (66°F) are approximately equal but, because of increased metabolic demand at the elevated level, energy reserves would be exhausted 1-1/2 to 2 times as fast at 19°C. This illustrates the common error of thinking that equal levels of performance call forth equal demands on metabolism.

The thermal requirement which can be expressed for any fish in the instance of temperature acting as a controlling factor becomes,

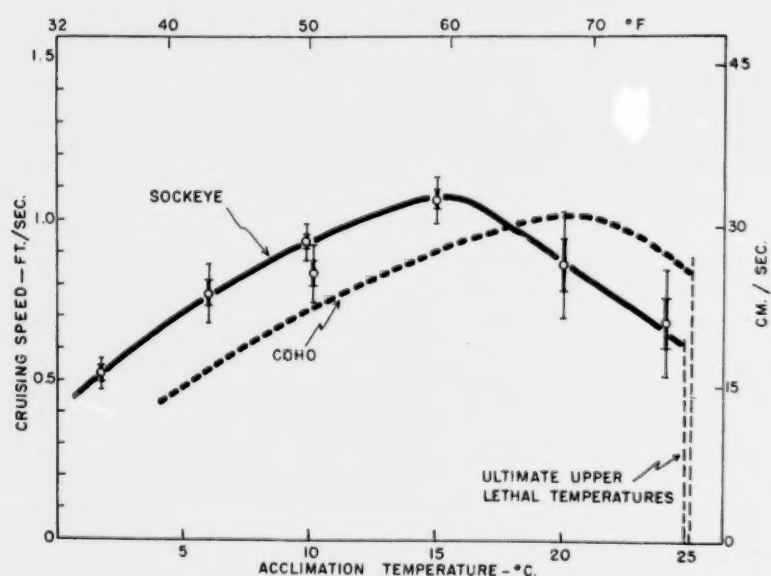


Figure 2. Variation in cruising speed for temperature acclimated underyearling sockeye and coho salmon, illustrating the greater activity of coho near the upper lethal temperature, and the converse relation for lower temperatures. (From Brett, Hollands and Alderdice, 1958).

* The author would appreciate any exceptions to this statement being drawn to his attention. It seems possible that there may be some intolerant endemic species in the most southern regions (but see Fries, 1952).

first, a level which will permit sufficient difference between resting and active metabolism to provide for essential activities, and second, since different species prosper at different levels, it is of distinct advantage to the animal to be at the lower level of metabolic demand for two equal levels of performance since the nutritional demand is reduced. This relation undoubtedly accounts in part for the decline in growth despite increased feeding which may accompany elevated temperatures. Baldwin (1956), while conducting an experiment on food consumption in brook trout (*Salvelinus fontinalis*) using live minnows, ran into the experimental problem that the trout were comparatively slow at catching the minnows at 17°C (63°F) and virtually incapable at 21°C (70°F), with the result that the trout ran the risk of starvation and energy loss from ineffective attempts at capture in the midst of plenty. This experimental hazard was solved by the simple expedient of clipping the caudal fins off the minnows. It serves to illustrate the relative problem of thermal requirements for the two species, each well within any lethal level.

Temperature -- cellular action, interaction and stress (the 1960 decade)

In the last year (1959) of the present decade, it is intriguing to peruse recent literature for the seeds of new and promising research. A good many lines of endeavour can be seen. Considerable increase in examining responses to temperature change at the cellular level, and seeking the basic mechanisms of acclimation, tolerance, and shifts in metabolic response with temperature can be expected.

For two decades Belehradek's 1935 monograph remained the most comprehensive treatment of temperature and life. This work has now been complimented by two books of comparable stature, that by Precht, Christophersen and Hensel (1955), and the symposium entitled "Influence of Temperature on Biological Systems", edited by Johnson (1957). In Belehradek's time no less than seven theories regarding the cause of heat-death were current. Most of these have been disproven or lost favour, although Heilbrunn (1948) continues to find questionable support for changes in the lipid structure of the cell membrane as the basic phenomenon for thermal adjustment and the ultimate cause of death. Precht *et al.* (loc. cit.) have brought a refreshing and more inclusive postulation to the

fore, based on protoplasmic viscosity, which, despite some possible shortcomings as seen at present (Fry, 1958), holds encouraging promise that a unifying concept for thermal acclimation and tolerance will emerge within the next decade. Their thesis that the thermal stability of the protein molecule relates to the extent of bound water provides a basis for cold-death, through loss of vital water from the cell.

Further, in relation to basic chemical theory, as Johnson (1957) points out, the understanding of the effects of pressure and temperature is emerging in greater significance with the realization "that the physiological effects of increased pressure are subject to profound modification, even reversal, by temperature".

Turning to the relation of the total organism and its environment, the further application of the factor approach (Fry, 1947) to examining the influence of identities like temperature, oxygen and pressure will provide greater analytic insight into the overall mode of action and interaction. There appears to have been some neglect of this penetrating approach in the past, which surely will not be so in the future. If such a relation as, say, the effect of temperature on the resistance of fish to sodium arsenite is under consideration, the difference between the response at 20°C and 25°C might be surprising, simply because temperature had entered the lethal sphere in its own right. A shift in the mode of action would have occurred. If the reverse situation is concerned - the effect of sodium arsenite on the temperature response of fish - then, since temperature is a multiple factor, a variety of questions are actually involved, viz., the effect on thermal resistance, on response to a gradient, on the Q_{10} of some activity, or on the thermal span for regulated osmotic balance. These relate to the effect of temperature when acting as a lethal, a directive, a controlling, or an accessory factor. Temperature can even become its own interacting factor.

With the multiple role of temperature bringing increased attention to the problem of interaction, there will come a natural shift of emphasis away from the consideration of requirements in regard to a particular environmental identity like temperature; but rather to the over-all characteristics of environments which permit high survival of the species. Cocking (1957, 1959) has begun to examine the

significance of long-term temperature effects where accessory factors are undoubtedly involved. Taking a leaf from the excellent research on the lobster *Homarus americanus* (McLeese, 1956; McLeese and Wilder, 1958), studies on the interaction of temperature, oxygen and salinity can be expected. Work in our laboratory has recently commenced on an analysis of these factors in relation to the resistance of young coho salmon (*O. kisutch*) to kraft mill effluent. The fruitful pursuit of performance studies is likely to continue, particularly in a comparison of different activities and their relative metabolic demands as influenced by temperature (Brett et al., 1958). Woven amongst these will be the stimulating question of environmental stress, its manner of action and its endocrine involvement (Prosser, 1957; Brett, 1958; Fortune, 1958). The products of this forthcoming decade will provide increased reason to view temperature as a subtle, all-pervading, complex environmental factor.

DISCUSSION

Throughout the research which has been but briefly treated or noted in the preceding comments, it has been possible to see a separating of the parts for laboratory study followed by a return to examining the organism as a whole, inseparably fused in a complex environment. At one time it seemed as though systematic documenting of lethal temperatures might provide a useful basis for establishing limits of distribution in nature. Although grossly apparent, with warm water species tending to have wider or higher tolerance limits, inconsistencies were too numerous for more direct use. By combining this basic information with the further knowledge of the scope for activity which accompanied the extremes of tolerable temperature, more profitable interpretations have been possible. Thus, the two species of Pacific salmon, sockeye (*O. nerka*) and coho (*O. kisutch*) have very similar upper lethal temperatures but inhabit quite different regions within the same watershed and exhibit differences in behaviour correlated in part with temperature characteristics of the environment. The possibility of a temperature-dependent causal mechanism became apparent only when it was shown that coho possess an ability to remain active in the region of their upper lethal temperature, whereas sockeye do not (Figure 2). For the lobster, this type of reduced performance is nicely illustrated

by a graph relating lethality and inactivity (Figure 3) from McLeese and Wilder (1958). The authors' comment, "Continued existence of the lobster would not be possible in the zones of inactivity although the temperatures themselves are not lethal".

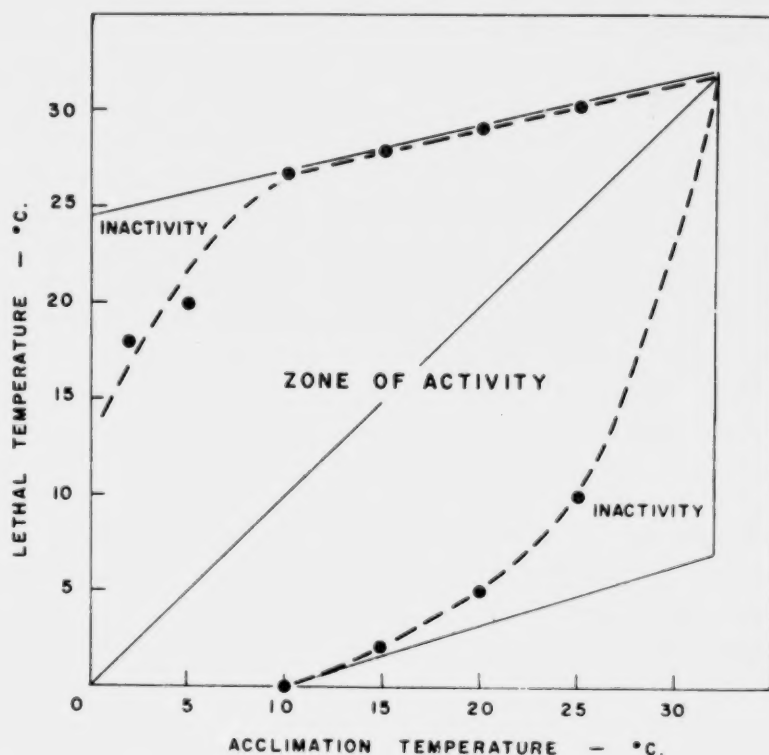


Figure 3. Thermal tolerance diagram for the lobster, showing zones of activity and inactivity where continued existence would not be possible. (From McLeese and Wilder, 1958).

The thermal requirement becomes, for a major portion of life, the need to be in a temperature range within which a fair measure of activity is possible. The phenomenon of temperature compensation in which the metabolic rate is favourably shifted to permit greater activity in poikilotherms inhabiting colder or warmer waters respectively, supports the above thesis concerning thermal requirements. To paraphrase the relation, at prevailing temperatures, the organism cannot afford to be numbed into inactivity nor be heated into the energy-draining maintenance of an excessive resting metabolism.

The homeotherm, by stabilizing internal temperature, despite the frequent cost of increased maintenance, has provided greater scope for activity for a wide range of external

temperatures. The poikilotherm, however, is denied this measure of control, and appears to rely on a fairly wide difference in metabolic rates despite changing temperature, within the range it normally inhabits (Figure 4).

Based on the deductions of the above discussion, and for the purpose of providing some starting point, it is proposed herewith that the upper limit of required temperature for any species of fish should not exceed that which

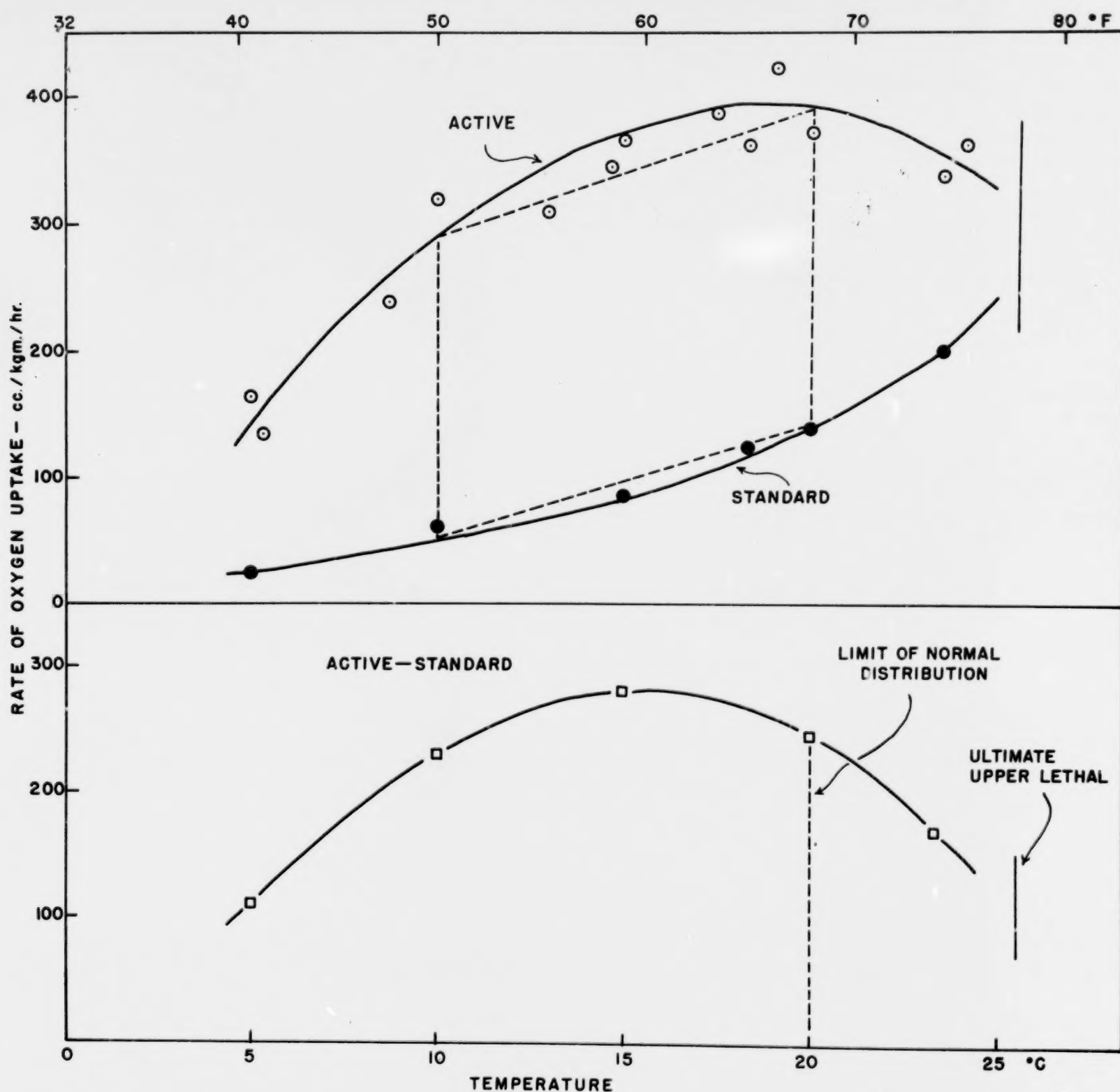


Figure 4. Relation of oxygen uptake to temperature in acclimated speckled trout. The difference between the active and the standard equals the scope for activity (From Graham, 1949). Limit of the normal distribution in warm water occurs at a temperature where the scope is about 4/5's of the optimum. An area in which the difference between active and standard metabolic rates is maintained at a relatively consistent level is indicated, i. e., where the scope is a flattened dome.

would curtail activity below $3/4$ of the optimum, i.e., $3/4$ of the maximum difference between active and resting metabolism. For those species which can maintain greater fractions of activity into the lethal range, a "freedom" of 3°C (5.5°F) below the ultimate lethal should be provided. In the case of lower temperature levels, the same metabolic or lethal temperature relation cannot be proposed, since it is annually demonstrated in ice-covered lakes that many species tolerate temperatures of a near lethal order for some months. Such things as infection, disease, parasitism, nutritional demand, and the general problems of competition and predation are often so reduced that a form of "hibernation" is possible near 0°C .

The above is set forth to invite discussion and appropriate research. It would only apply to the free-living fish, not the embryo, nor the spawning adults, and presumes that other environmental factors remain within normal bounds. Two remaining points should be made. At no time have preferred temperatures been introduced. Such levels can hardly be considered requirements; however, they have received significance in some instances by being

related to the temperatures which provide for maximum scope for activity (Fry, 1947). Finally, temperature tolerance studies for every stage in the life cycle are sorely needed (Figure 5), particularly at the level of the developing embryo. Seymour (1956) has recently contributed to this need by a study of the effects of temperature on incubation and hatching in chinook salmon eggs. If the profitable studies on embryonic temperature adaptations in the frog (*Rana pipiens*) by Moore (1949) and Volpe (1957) can be taken as an indication of the value for similar studies among fish, the concepts of thermal requirements will be considerably abetted.

In conclusion, life is only possible for very brief periods outside the zone of thermal tolerance. Within it, the energy demands of a competitive life, the particular requirements for spermatogenesis or oogenesis, and the need for a relatively stable cellular environment, impose limitations on thermal experience if the species is to survive at a respectable level. Until these subtleties are better understood, provision for a definite measure of activity must be afforded to meet the problem of thermal requirements.

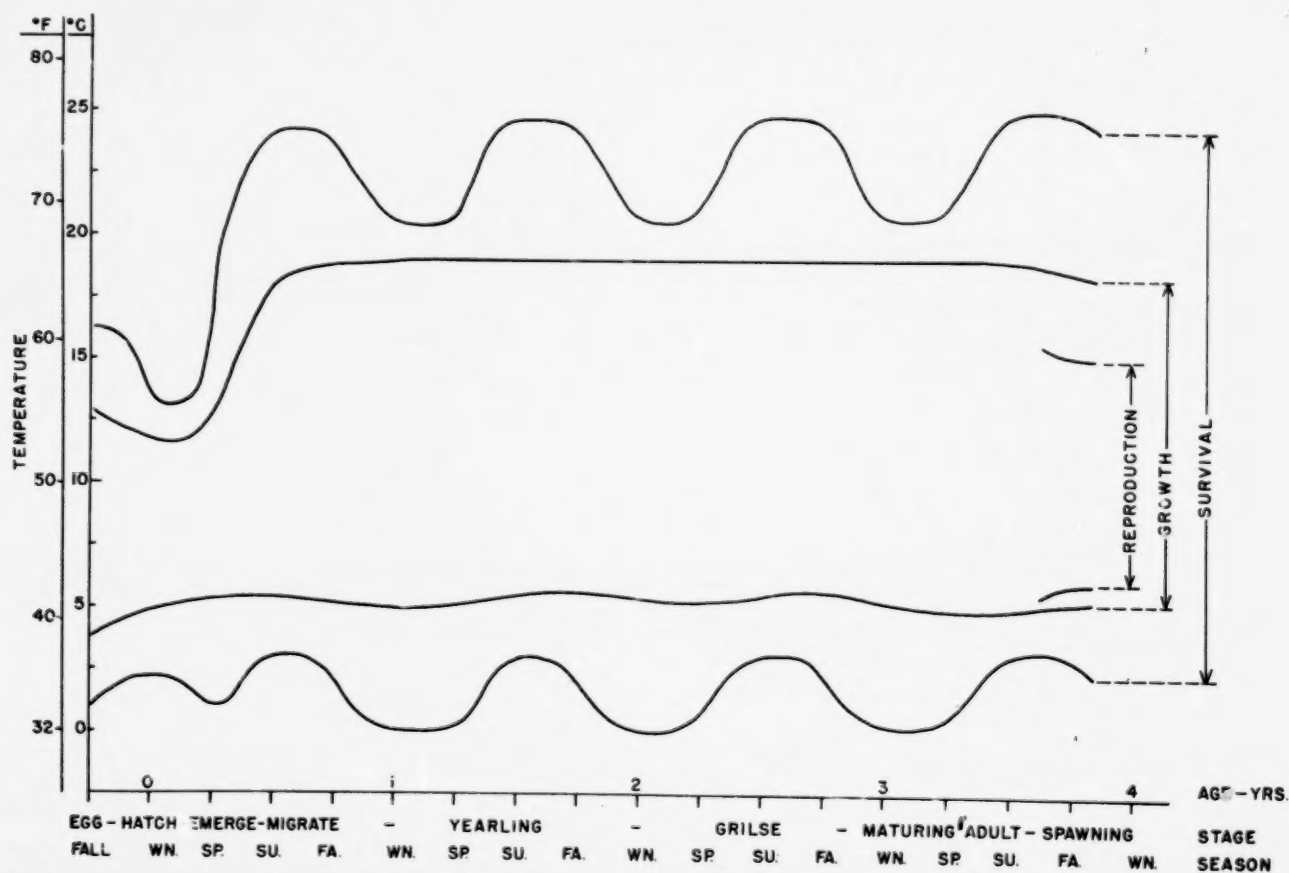


Figure 5. Schematic representation of thermal requirements for different life processes which characterize Pacific salmon. Freely compiled by reference to Donaldson and Foster, 1941; Brett, 1952; Brett and Alderdice, 1958; Seymour, 1956; Annual Reports of the International Pacific Salmon Fisheries Commission.

REFERENCES

- Bailey, R.M. 1955. Differential mortality from high temperature in a mixed population of fishes in southern Michigan. *Ecology*, 36(3): 526-528.
- Baldwin, N.S. 1957. Food consumption and growth of brook trout at different temperatures. *Trans. Am. Fish. Soc.*, 86: 323-328.
- Belehradek, J. 1935. Temperature and living matter. *Protoplasma monographien* 8, Berlin, 229 pp.
- Brett, J.R. 1946. Rate of gain of heat-tolerance in goldfish (*Carassius auratus*). *Univ. Toronto Stud., Biol. Ser.*, 53 (Pub. Ont. Fish. Res. Lab., 64): 9-28.
- Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *J. Fish. Res. Bd. Canada*, 9(6): 265-323.
- Brett, J.R. 1956. Some principles in the thermal requirements of fishes. *Quart. Rev. Biol.*, 31(2): 75-87.
- Brett, J.R. 1958. Implications and assessments of environmental stress. In "The Investigation of Fish-Power Problems", ed. P.A. Larkin. *H.R. MacMillan Lectures in Fisheries*, Univ. of British Columbia, pp. 69-93.
- Brett, J.R. and D.F. Alderdice. 1958. The resistance of cultured young chum and sockeye salmon to temperatures below 0°C. *J. Fish. Res. Bd. Canada*, 15(5): 805-813.
- Brett, J.R., M. Hollands and D.F. Alderdice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. *J. Fish. Res. Bd. Canada*, 15(4): 587-605.
- Bullock, T.H. 1955. Compensation for temperature in the metabolism and activity of poikilotherms. *Biol. Rev.*, 30(3): 311-342.
- Cocking, A.W. 1957. Relation between the ultimate upper lethal temperature and the temperature-range for good health in the roach (*Rutilus rutilus*). *Nature*, 180: 661-663.
- Cocking, A.W. 1959. The effects of high temperatures on roach (*Rutilus rutilus*). I. The effects of constant high temperatures. *J. Exp. Biol.*, 36(1): 203-216.
- Cocking, A.W. 1959. The effects of high temperatures on roach (*Rutilus rutilus*). II. The effects of temperatures increasing to a known constant rate. *J. Exp. Biol.*, 36(1): 217-226.
- Donaldson, L.R. and F.J. Foster. 1941. Experimental study of the effect of various water temperatures on the growth, food utilization, and mortality rate, of fingerling sockeye salmon. *Trans. Am. Fish. Soc.*, 70: 339-346.
- Doudoroff, P. 1942. The resistance and acclimation of marine fishes to temperature changes. I. Experiments with *Girella nigricans* (Ayres). *Biol. Bull.*, 83: 219-244.
- Fortune, P.Y. 1958. The effect of temperature changes on the thyroid-pituitary relationship in teleosts. *J. Exp. Biol.*, 35(4): 824-831.
- Fries, E.F.B. 1952. Observations on chill tolerance and applied chill coma in subtropical American marine fishes, especially *Bathygobius*. *Copeia* (3): 147-152.
- Fry, F.E.J. 1947. Effects of the environment on animal activity. *Univ. Toronto Stud., Biol. Ser.*, 55 (Pub. Ont. Fish. Res. Lab., 68), 62 pp.
- Fry, F.E.J. 1958. Temperature compensation. *Ann. Rev. Physiol.*, 20: 207-224.
- Fry, F.E.J., J.R. Brett and G.H. Clawson. 1942. Lethal limits of temperature for young goldfish. *Rev. Can. de Biol.*, 1: 50-56.
- Graham, J.M. 1949. Some effects of temperature and oxygen pressure on the metabolism and activity of the speckled trout, *Salvelinus fontinalis*. *Canadian J. Res.*, D, 27: 270-288.
- Hart, J.S. 1947. Lethal temperature relations of certain fish in the Toronto region. *Trans. Roy. Soc. Canada*, 41(3): 57-71.
- Heilbrunn, L.Y. 1948. *An Outline of General Physiology*. W. B. Saunders, Philadelphia, Pa., 2nd ed., 748 pp.
- Johnson, F.H., ed. 1957. Influence of temperature on biological systems. *Am. Physiol. Soc.*, Washington, D.C., 275 pp.
- McLeese, D.W. 1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. *J. Fish. Res. Bd. Canada*, 13(2): 247-272.
- McLeese, D.W. and D.G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. *J. Fish. Res. Bd. Canada*, 15(6): 1345-1354.
- Moore, J.A. 1949. Patterns of evolution in the genus *Rana*. In "Genetics, Paleontology and Evolution", eds., Jepsen, G.L., E. Mayr and G.G. Simpson. *Princeton Univ. Press*, pp. 315-338.
- Precht, H., Christophersen, J. and Hensel, H. 1955. *Temperatur und Leben*. Springer Verlag, Berlin, Germany, 514 pp.
- Prosser, C.L. 1957. The species problem from the viewpoint of a physiologist. In "The Species Problem", *Am. Ass. Adv. Sci.*, Washington, D.C., pp. 339-369.
- Seymour, A.H. 1956. Effects of temperature upon young chinook salmon. Ph.D. thesis, Univ. Washington, Seattle, Washington, 127 pp.
- Spector, W.S., ed. 1956. *Handbook of Biological Data*. W. B. Saunders Co., 584 pp.
- Sumner, F.B. and P. Doudoroff. 1938. Some experiments upon temperature acclimatization and respiratory metabolism in fishes. *Biol. Bull.*, 74: 403-429.
- Volpe, E.P. 1957. Embryonic temperature adaptations in highland *Rana pipiens*. *Amer. Nat.* 91(860): 303-310.

SETTLEABLE SOLIDS, TURBIDITY, AND LIGHT PENETRATION AS FACTORS AFFECTING WATER QUALITY

Alfred F. Bartsch, Water Supply and Water Pollution Research
Robert A. Taft Sanitary Engineering Center

ABSTRACT

A few water pollution control agencies have adopted specific criteria to protect fish and other aquatic life from settleable solids and turbidity. A general lack of information on the effects they produce has caused other agencies to forego establishing criteria at this time. While the individual elements can be examined separately, settleable solids, turbidity and light are so interrelated as to require additional discussion as a single factor affecting the environment.

Settleable solids include inorganic particles from soil erosion and various industrial operations as well as living and dead suspended organic matter of natural or man-influenced origin. Particles that settle on the bottom can destroy fish food organisms, interfere with successful hatching of fish eggs, obliterate otherwise suitable spawning areas and carry unstable organic matter to the bottom where undesirable decomposition products are formed. While sus-

pended, particles in sufficient concentration or of sufficient hardness and size may directly injure fishes and fish food animals. Specific cases that exemplify some of these effects are described.

Suspended particles also affect the optical properties of water so as to create turbidity. By impairing light penetration, turbidity diminishes the thickness of the euphotic zone and this limits basic productivity. Rates of photosynthesis in relation to light extinction in a raw sewage stabilization pond and in the Ohio River near Cincinnati are discussed. Quantities of phytoplankton in clarified and turbid waters of the Missouri River are another expression of impairment of basic productivity by turbidity. Turbidity may also affect temperature relations. In sport fishing waters, turbidity limits the distance at which sport fish can see the lure and thus affects both the yield and attractiveness of fishing waters.

Because of the damaging influence of settleable solids and turbidity upon the aquatic environment, a number of State and interstate water pollution control agencies have adopted criteria for the protection of fish and aquatic life. Specific figures on allowable concentrations of settleable solids are rare in contrast to more general prohibition against conditions conducive to the formation of damaging sludge banks. General rather than specific criteria to protect aquatic life from turbidity are the rule also. Where exact turbidity values have been specified in terms of allowable maxima, they range from 10 to 250 ppm.

In discussing settleable solids in relation to aquatic life, the Aquatic Life Advisory Committee of ORSANCO (Anon., 1956^a) took the following position:

"Since there is a lack of exact information concerning the effects of settleable solids on fish-food production, fish spawning, and phytoplankton production, no criteria on the amount of such material which may be added safely to a stream can be formulated at this time. It is

recommended, however, that organic wastes not be added to a stream in such quantity that they alone or in combination with inorganic materials form sludge beds or change the physical nature of the bottom."

Settleable solids, turbidity, and light are separable entities and each has specific influences upon the aquatic environment. Each is also so closely involved with the other that some aspects of their interaction must be discussed as a single problem area.

As used here, the term, settleable solids, includes particulate matter capable of settling but which may be suspended, in the act of settling, or settled. Such solids may be organic or inorganic; they may originate inside or outside the water basin. They are also referred to as sediments or suspensoids. While in suspension, such particulate matter is responsible for turbidity or interference with the pattern of light penetration. Although particles in suspension may directly damage aquatic organisms, bottom deposition and light extinction are the two

factors of chief concern to biologists. Each of these factors is discussed separately.

SETTLEABLE SOLIDS

Perhaps the best known waterborne sediment is silt, consisting of rock particles or sand or clay lost from the land through erosion. In spite of increased erosion control, tremendous quantities of soil still leave the land and start toward the sea. It is said that the topsoil of one 40-acre farm passes a given point on the Mississippi every minute of the day and night (Newcombe, 1951). The Potomac also is not immune to this receipt of silt. In 1948 the mudload at Washington, D. C. was 1.7 million tons (Kemp, 1949). Among the familiar muddy rivers in the country are the Missouri, Yellowstone, and Rio Grande.

Sediments also include the particulate solids resulting from mining, dredging, gravel and coal washing, ore concentrating, precipitating industrial dusts, cleaning of cotton and wool, and irrigating. Of similar influence upon the aquatic environment are sawdust, bark, chips, and lost wood fibers from forest products industries, and the solids in sewage and miscellaneous industrial wastes.

Much already has been written on the effects of deposited sediments upon waters and their productivity. Changes in Chesapeake Bay resulting from deposited erosion silt and concurrent damages to oyster production are well known. Colonial towns, once adjacent to the Bay, now are stranded inland one or two miles. Erosion silt - much of it from mining operations - once flowed into San Francisco Bay, until today more than 40 percent of the Bay area is less than five feet deep (Newcombe, 1951). Changes in large bodies of water such as these come so slowly that the extent of the potential damage frequently is not obvious until the point of economic salvage has been exceeded. In tributary fishing streams this situation is less likely, especially if the sediments have an industrial origin. Yet, siltation is regarded as one of the most important factors impairing otherwise desirable fishing waters; however, quantitative data on such impairment are not available.

The influence upon fauna of sedimentation from improper logging operations was studied in a North Carolina Appalachian watershed by Tebo (1955). Downstream from the logged

watershed, pools and riffles were covered with a layer of unproductive sand and micaceous material up to ten inches thick. During the period of maximum sediment accumulation, the standing crop of bottom fauna was drastically reduced as contrasted with unaffected habitats upstream.

Similar studies have been made by Davidson (Bowers, 1955, Anon., 1956a) on the Coal River Drainage Basin in West Virginia where sediments from numerous coal washeries had blanketed the bottom and seriously destroyed productivity. A pollution abatement program instituted by the State Water Commission has progressed sufficiently to permit restocking with fish as a step toward reclaiming these waters for sport fishing. Similar findings of damage resulted from studies on the Powder and Burnt Rivers in Oregon where suspended pollutants, originated in gold dredging operations (Wilson, 1953), increased turbidity from a natural level of about 5 ppm. to 1700 ppm. Concurrently, density of fish-food organisms dropped to almost zero but was restored progressively downstream to a level of >2 grams per square foot as turbidity decreased to 17 ppm. In the sediment polluted waters, rainbow trout, whitefish, and cottids disappeared and were replaced by suckers and squawfish.

Another example of sedimentation of industrial origin has its setting on a small tributary of the Potomac River. High-grade quartzite sand mined nearby is crushed in preparation for glass manufacture. Inert wastes from the washing process reach the Potomac through this small tributary. After sedimentation over a three-mile flow, turbidity at the mouth of the tributary was found to exceed 5000 ppm. and suspended solids 7650 ppm. Because of complaints, a survey was made to assess the damages (Bartsch, 1953) to sport fishing in the area.

On both sides of the river at mileage point -0.1*, the bottom was composed principally of smooth, coarse gravel deposited over and mostly covering inclined sedimentary rock (Figure 1). Attached algae were common, and the water was exceptionally clear. The standing crop of bottom fauna was practically the same on both sides of the river:

	No./Sq.Ft. Sample	No. of Genera or Species	cc/Sq.Ft. Sample
Right Side	41	13	2.6
Left Side	44	15	2.8

* 0.1 mile upstream from entry point of waste.

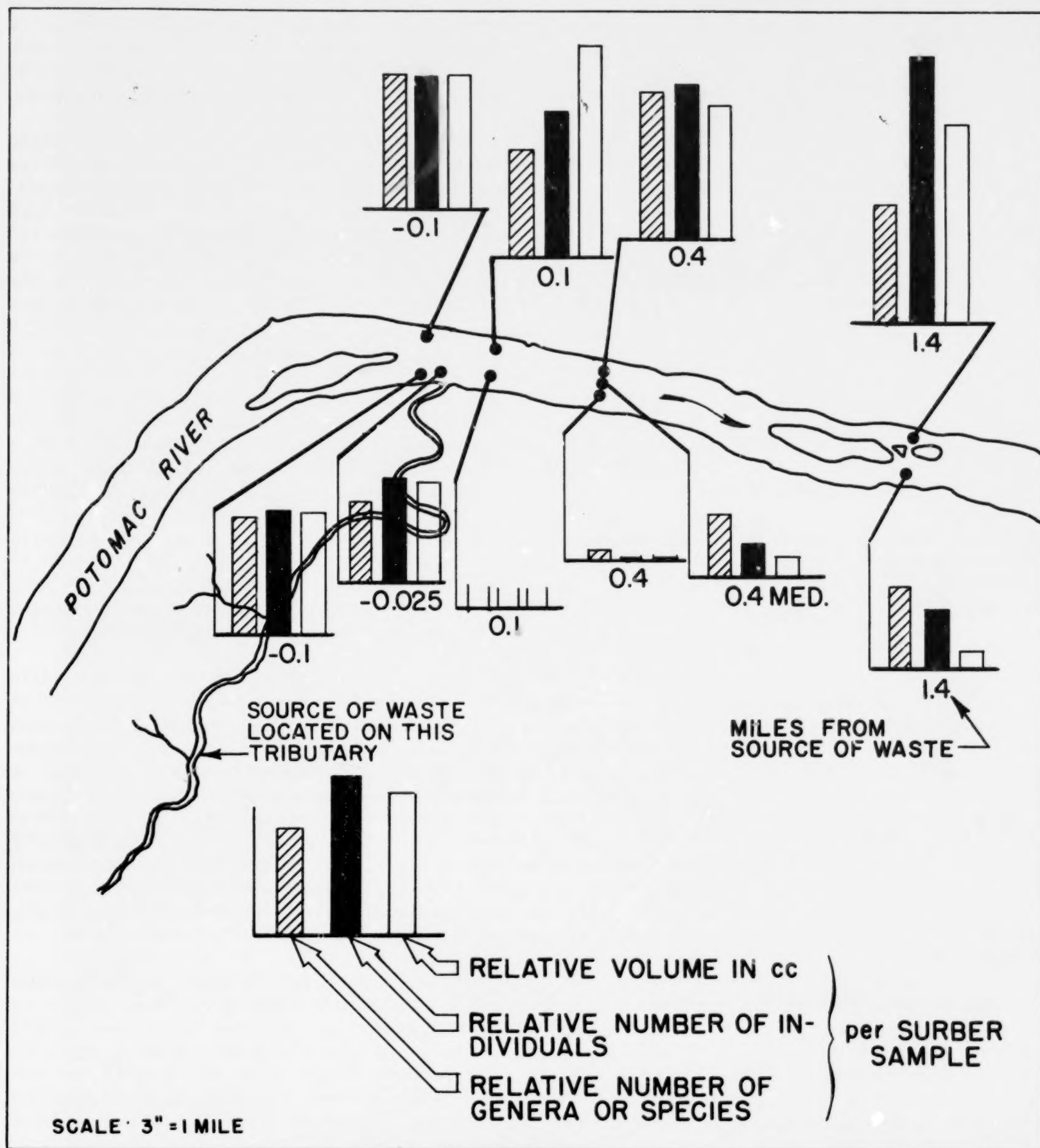


Figure 1. Standing crop of animals in areas affected by increased settleable solids and turbidity - Potomac River, 1952

At station 0.0, the mouth of the tributary, the bottom was composed of fine, sandlike sediment that yielded to pressure of walking and responded like quicksand. There were no bottom fauna. From this point, the load of suspended sediment was swept into the river and moved downstream, initially restricted to the right bank. The heavier particles formed a delta that extended fan-like out into the river and downstream.

Five hundred feet downstream the bottom consisted of fine, light colored sand 18 inches thick. Turbidity was 575 ppm., decreasing to 77 ppm. at midstream. Progressing toward the opposite side, an occasional stone became visible near midstream until, farther across the bottom finally consisted of stones embedded in and surrounded by fine sand. There were no algae, rooted plants, or bottom fauna on the right side of the river* whereas the left side was normal.

Four-tenth of a mile downstream, increased turbidity extended over two-thirds the width of the river. Semisolid fine sand covered one-third the river bed. The middle third was a mixture of rubble and sand, finally giving way to rubble with sand between the stones. Mean volume of bottom fauna per Surber sample (Table 1) shifted from < 0.1 cc near the right bank to 0.4 cc at midstream and to 2.8 cc near the left bank. Turbidity changes were in reverse order with a high of 550 ppm. where the bottom crop was < 0.1 cc.

Between 1.4 and 2.4 miles downstream, river channel conditions apparently are such that settleable solids are deposited in some degree across the entire river bed. The fine sand packed around stones on the left side was similar in texture to that partially or completely covering stones on the right side. Yield of bottom fauna was < 1 cc at both sides.

Table 1. Standing crop of animals in areas affected by increased settleable solids and turbidity.

Potomac River, 1952

Station**	Number of genera or species		Mean number of animals/Surber sample		Mean volume (c.c.) of animals/Surber sample		Turbidity ppm	
	Left***	Right	Left	Right	Left	Right	Left	Right
-0.1	15	13	44	41	2.8	2.6	<25	<25
0.0	0		0		0		> 5000	
0.1	13	0	48	0	4.5	0	<25	575
0.4	16	1	51	1	2.8	<0.1	<25	550
0.4 Mid	7		11		0.4		35	
1.4	13	9	89	19	4.2	0.3	<25	60
2.4	12	6	27	17	0.9	0.9	<25	82
4.9	11	10	59	20	2.9	0.6	<25	<25
9.4	16	10	89	36	3.4	0.7	<25	<25
13.1	12	15	71	67	4.6	2.7	<25	<25

* Looking downstream.

** Miles below or above (-) the point of waste entry.

*** Right and left banks determined when facing downstream.

Extending downstream along the right bank of the river some 10-13 miles from the point of waste entry, a strip of bottom varying from one-third to one-half or more of the river width had less animal life than above and below this zone (Figure 2). Productivity depression was most pronounced in the volumes and population densities per unit area but also was clear cut with respect to variety of animals at each station. Bottom life was absent in the fan-shaped deposit area at and downstream from the tributary. This condition persisted for at least 0.1 mile, and for at least 1.4 miles production did not ex-

ceed 12 percent of that occurring above pollution and 36 percent for 9.4 miles.

The influence upon the river of sand washing wastes are ability to increase turbidity, tendency to settle on the bottom even with fairly high flow velocities, and power to sand blast or abrade. Settling particles pack around the gravel and rubble like wind-blown snow, filling the minute cracks and crevices that give such bottoms their tremendous productive area. Simultaneously, they also grind away at the biotic remnant persisting in the darkness where photo-

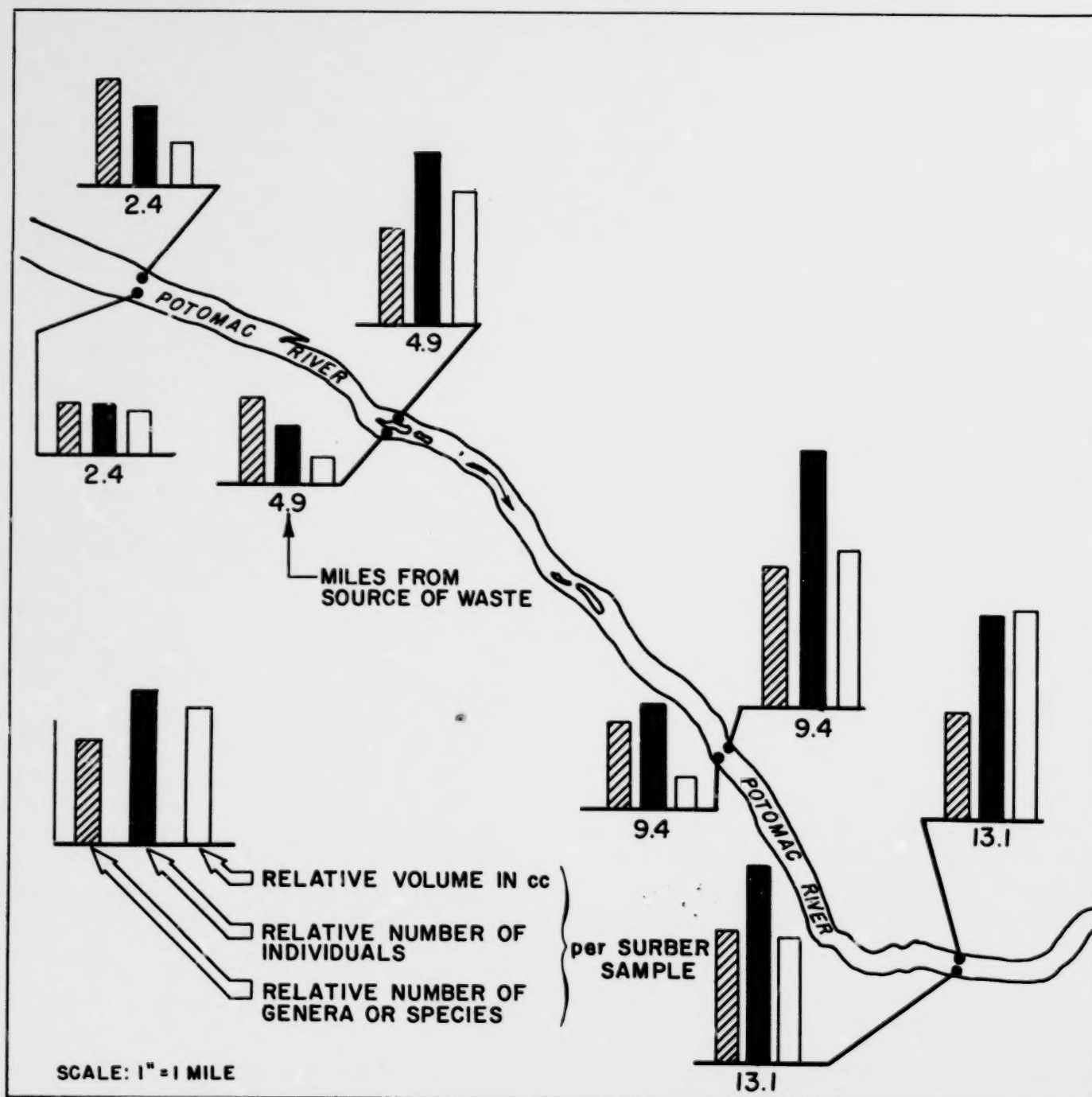


Figure 2. Standing crop of animals in areas affected by increased settleable solids and turbidity - Potomac River, 1952

synthesis is of little consequence. Impairment of water quality and recreational usefulness of the river result from the combined effects of these actions.

Observations on fish and fish-food organisms have been made by others on the effects of increased sedimentation from placer and dredge mining, and the dismal findings almost always have been the same. In studies of the Rogue River in Oregon, Ward (1938a, 1938b) concluded that there was no damage to the river or its fishery. Unfortunately, although these views were referenced solely to the Rogue, on occasion they have been cited as proof that mining silt is harmless. The opposite view has been expressed vigorously by Smith (1939). In this country the influence of inorganic sediments upon hatchability of trout and salmon eggs has been studied by Shapovalov (1937). In later studies by Shaw and Maga (1943), fertile eggs in gravel were exposed 2 to 4 hours on selected days to water containing 1176-1330 ppm. of suspended solids from gold dredging operations. The principal effect noted was reduction in average yield of fry from 16.2 percent in normal hatchery water to an average yield of 1.16 percent in silt-bearing water. These studies also showed that the earlier in the incubation period the silt was applied, the greater was the reduction in fry yield, which finally reached zero. Undeveloped eggs were found to be coated and preserved with silt.

Less commonly noted is the ability of inert particles to settle organic flocs and adsorb finely dispersed organic matter and carry it to the bottom. Core samples of the Potomac River taken in the Washington Metropolitan Area during 1952 (Bartsch, 1954) showed sediment deposits from 1.5 to more than 10 feet thick. Ebullition of gas was evident over much of the river surface above soft deposits covered with coarse sand. Frequently the cores consisted of alternating strata of differing consistency, color, and odor, suggesting periodic deposition of decomposable organic matter. This action of inorganic settleable solids by which oxygen-demanding substances are incorporated into the otherwise inert bottom materials sets the stage for such objectionable anaerobic conditions.

Particles of decay-resistant organic matter can cause special problems when they accumulate on the bottom. Best known perhaps are wood fibers lost in the process of pulp and paper

making, frequently accompanied by water soaked fragments of bark and lost chips. Some idea of the potential magnitude of the problem can be derived from wood pulp production data (Anon., 1958). Total production for all processes was about 22 million tons per year for 1955, 1956, and 1957. If fiber losses are assumed to approximate 1 percent of production, the load to streams is more than 200,000 tons per year. In quiescent areas the fibers settle out and blanket the stream bottom, frequently destroying spawning and food producing areas. In some areas such fiber deposits, mixed with slime growths and supporting numerous oligochaetes, were found to be nine feet thick. Rising water temperatures following a colder period of fiber deposition often permit trapped gases from accelerated fermentation to float unsightly fiber mats to the surface. Episodes of this kind occurred in many streams in the country and have been seen on the Lower Fox, Wisconsin, and Flambeau (Bartsch, 1949) Rivers in Wisconsin. Similar floating mats have been noted on the Spanish River in Ontario (Dymond and Delaporte, 1952) where extensive study showed deposits up to two and one-half feet thick extending downstream more than 20 miles from the point of origin. In the first 20 miles, average coverage of the bottom was 22 percent by fiber, 20 percent by bark, and 20 percent by wood chips.

More recently, studies of the Penobscot River in Maine (Everhart, Watson, and Cutting, 1955) showed deposits of wood fiber and other pollution sufficient to preclude effective management of the Lower West Branch for restoration of Atlantic salmon. Boiling decomposition gases often floated to the top large mats, some 50 feet square and 15 inches thick. Fish-food organisms were absent, and test netting produced neither trout nor salmon.

Fortunately, corrective efforts continue and new practices and equipment help decrease this kind of pollution from the pulp and paper industry. A number of these developments have been described by Van Horn (1953).

TURBIDITY

Wallen (1951) conducted tests with montmorillonite clay turbidity on 16 species of fishes. He found that most fishes tested endured exposures to 100,000 ppm. of turbidity for a week or longer but finally died at turbidities of 175,000 to 225,-

000 ppm. Opercular cavities and gill filaments of those that died were clogged with the clay particles, but macroscopic or microscopic examination gave no evidence of injury to gills or body surface. If one recalls that turbidities in even the "Big Muddy" Missouri from Williston to Yankton rarely exceed 7000 ppm., it seems unlikely that natural turbidities will be directly lethal.

Ellis (1944) has stated that particles with a hardness greater than one, if large enough, will injure gills and other delicate, exposed tissues of fishes, molluscs and insects. Tests have shown that rock powders, blast furnace slag, cinder particles, and coal washings are injurious if they pass a 7000-mesh screen. Injury is apparently not the result with suspended materials as soft as wood fiber, for Cole (1935) found that some fishes are able to live for three weeks in a 20,000 ppm. suspension. Damage to gill tissues was not found in these fishes.

Increased turbidity, the second influence of suspended particles, expresses the optical property of water, permitting it to scatter and absorb light. The particles may consist of clay, silt, finely divided organic matter, plankton, and other microorganisms. Although sometimes expressed in ppm., turbidity is not really a measure of the weight of suspended matter. Turbidity affects the water environment by rapidly absorbing radiant energy in the upper layers of water and reducing the depth of effective photosynthesis. It may also affect temperature relations and finally, make sport fishing waters unattractive and less productive. Each of these effects is discussed briefly.

Much has been written on the optical properties of lakes and the penetration patterns of natural light and its component wave lengths. The studies of these phenomena by Birge and Juday (1929, '30, '31, '32) are well known. It will suffice here to recall that extinction of light is logarithmic with depth; rate of light intensity decrease with depth is uniform in a vertically homogeneous water; all wave lengths are not absorbed uniformly; and transparency is inverse to both color and turbidity.

Natural waters vary considerably in the extent to which they absorb light. The nature of their absorptive properties frequently is expressed as the depth at which 1 percent of the surface light remains. Some idea of the ab-

sorptive range in a given geographic area is shown by a 1 percent light depth of about 0.75 meter in Helmet Lake and about 19 meters in Crystal Lake, both in Wisconsin.

This superficial layer which absorbs 99 percent of surface light generally is considered the stratum in which all appreciable photosynthesis occurs. Utilization of solar energy in relation to primary productivity and oxygenation makes it pertinent to examine the absorptive characteristics of several waters. The Ohio River (Figure 3) is an example of a vertically homogeneous medium having a euphotic zone 1.26 meters thick. In contrast, the raw sewage stabilization pond shown absorbed 99 percent of the light in as little as 7 centimeters. Murdo Lake exhibits an absorption pattern where either color or turbidity increases with depth. Variable absorption at different depths reflects unequal vertical distribution of turbidity. In the raw sewage pond shown, variable extinction was caused by unequal distribution of phytoplankton. Similar variations in Western Lake Erie (Chandler, 1942) were caused chiefly by density differences in inorganic suspensoids.

In considering the many influences that suspended materials may have upon aquatic environments, Ellis (1936, 1944) recommended that the "millionth intensity depth" (m.i.d.) of water for good fish production should be not less than 5 meters. When translated to the 1 percent depth, which is more easily visualized, this figure becomes about 1.4 meters - a value similar to that reported above for the Ohio River.

Impairment of photosynthesis by high turbidity can be demonstrated readily. In the raw sewage pond cited, where turbidity is largely due to phytoplankton, gross oxygen production per hour becomes inconsequential below 60.9 centimeters where only 3 percent of the surface light remains (Table 2). This relation would exist in principal regardless of the organic or inorganic nature of the turbid particulate matter.

In the Ohio River, when the 1 percent depth was between 1 and 1.5 meters, light and dark bottles were used to measure photosynthetic oxygen production at three depths. These tests indicated oxygen production in the euphotic zone at a daily rate of about 6.4 grams per square meter (57 pounds per acre) per day (Figure 4). During the same period respiratory use was about 5.0 grams per square meter - a P/R ratio

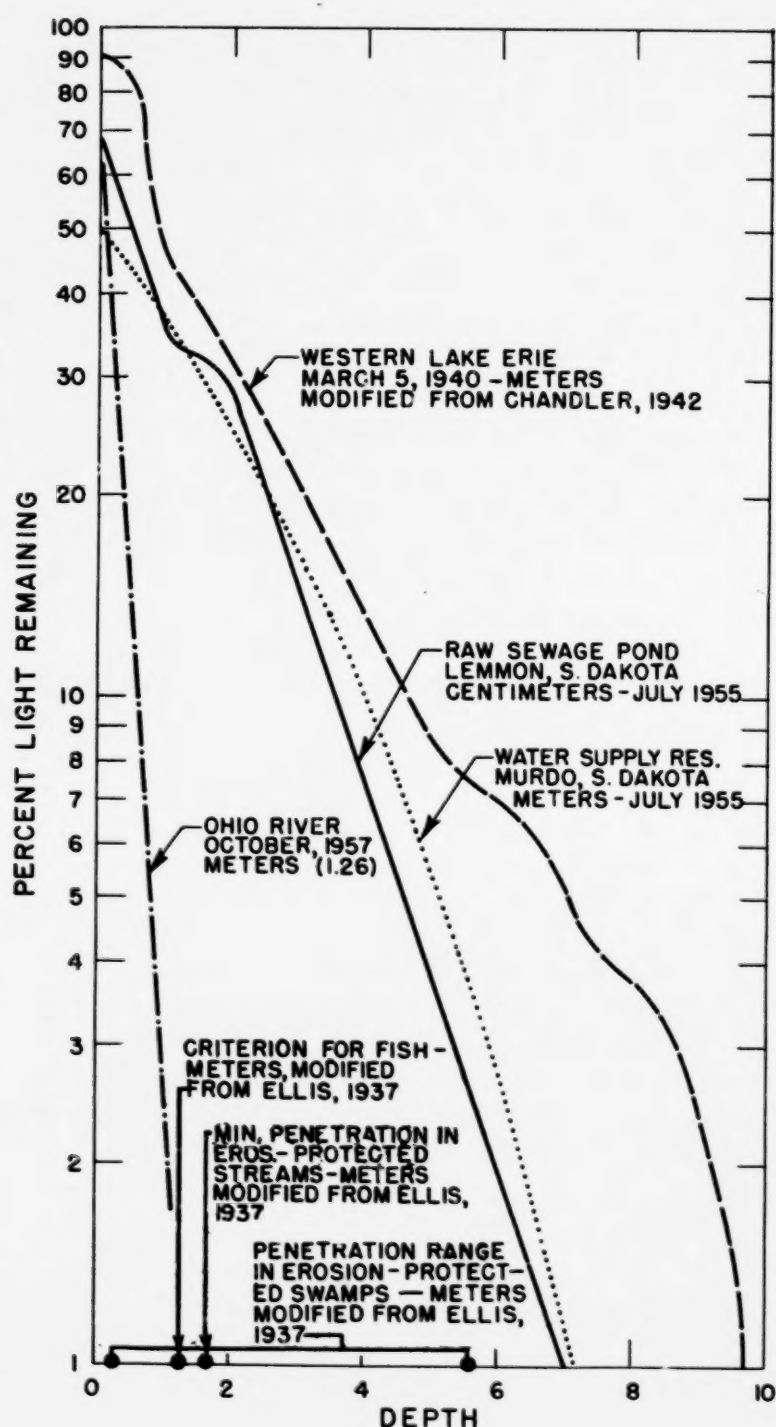


Figure 3. Light penetration in several fresh waters.

of 1.3. In a stream like the Ohio, the surplus oxygen can be available and valuable for waste stabilization. This output also is evidence of basic food production and a start toward a harvestable fish crop.

The influence of turbidity can be shown by indirection also. Prior to the construction of the five big dams on the Missouri River, the "Big Muddy" was not appreciably productive of phytoplankton. At present, the much impounded,

Table 2. Photosynthetic oxygen production in relation to light intensity at different depths.

Raw Sewage Pond, Lemmon, S. Dak.
August, 1955

% Surface light	Approx. ft. candles	Depth cm.	Oxygen production ppm/hr.	Respiratory use ppm/hr.
19.0	1050	25.4	2.9	0.4
3.1	167	60.9	0.4	0.4
0.5	27	96.5	0.1	0.4
0.07	3.8	134.6	0.04	0.4

less turbid river supports an increased growth of algae, sometimes to the point of causing problems in municipal water supplies. Studies by the Public Health Service (Anon., 1954) have followed the productivity changes that accompanied decreasing turbidity. Despite other possible factors, this relationship below Ft. Randall Dam before and after impoundment is shown in Figure 5.

Basic data for the country (Anon., 1955) in terms of numbers of licensed fishermen, expenditures for the privilege of fishing, and yield per man-period of fishing effort indicate beyond doubt that the average sport fisherman fishes for recreation and not merely to carry home food for the table. Nor does he fish where there is little prospect of success or in surroundings which fail to contribute to the recreation of "being out fishing". To many fishermen, such recreation means that chronically turbid waters are lost as fishing places.

Every fisherman knows that fishing for bass, trout, and many other game fishes is not rewarding when normally clear waters are muddied by heavy rain or other cause. Game fishes normally feed by sight. As turbid water clears, the field of vision increases and the fish are able to see their food as well as the fisherman's lure at greater distances. Data for Fork Lake in Illinois (Bennett, Thompson and Parr, 1940) have shown a striking correlation between transparency of the water and numbers of large-mouth bass and bluegills caught:

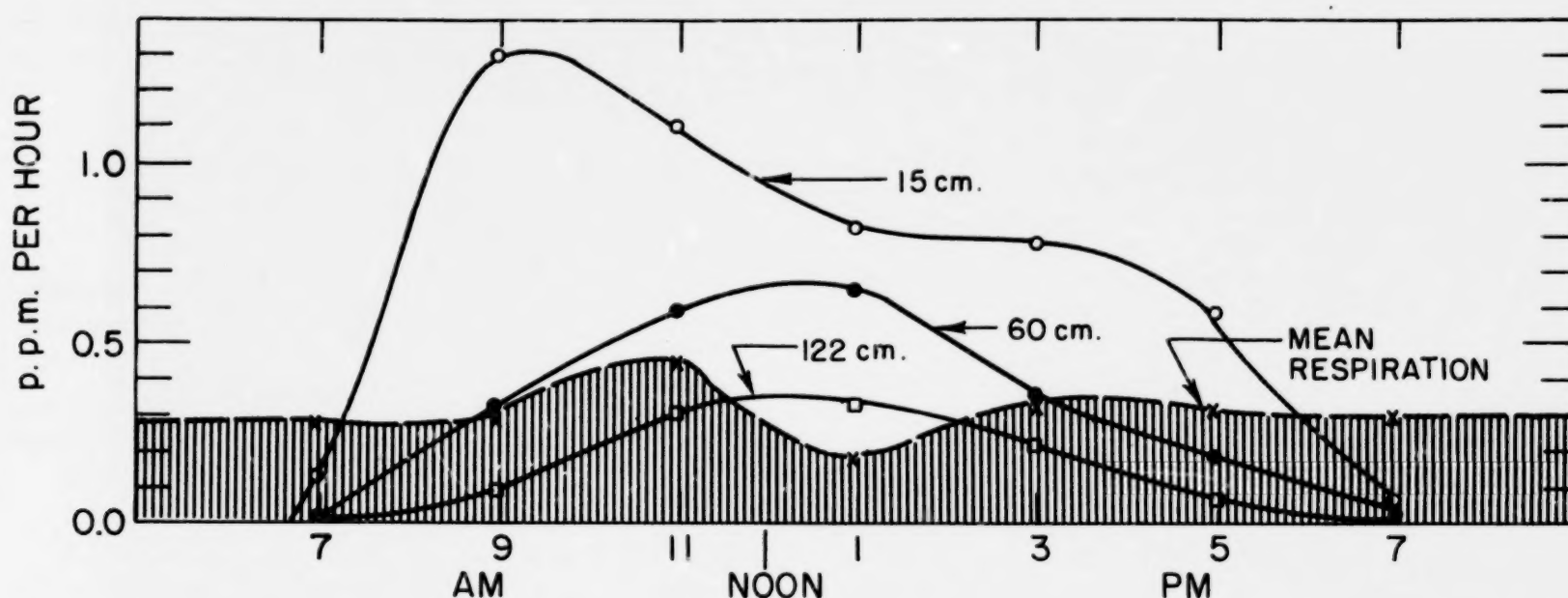


Figure 4. Respiratory use and D.O. production at three depths in Ohio River, Bromley - October 3, 1957.

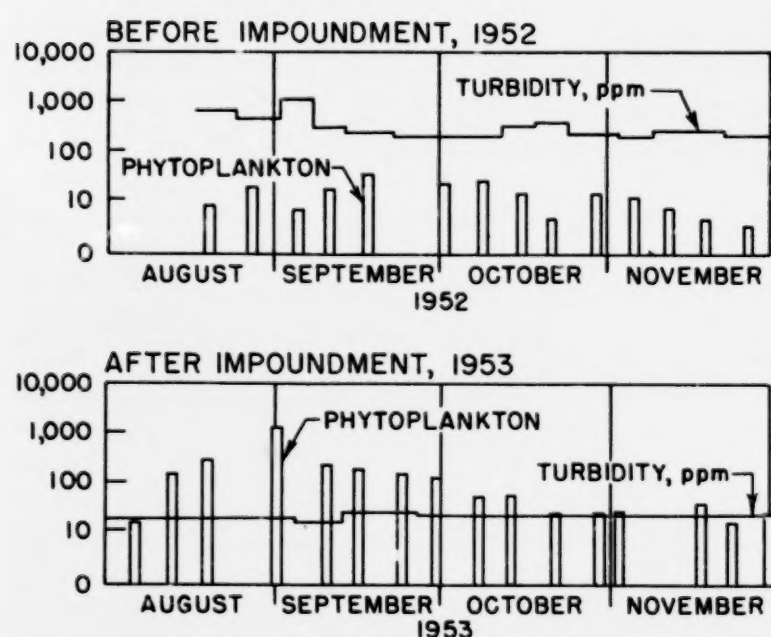


Figure 5. Relative quantities of phytoplankton in relation to turbidity, below Ft. Randall Dam, South Dakota.

(Modified from reference Anon. 1954)

Transparency, feet	Fish caught per man-hour
0.5 - 2.0	2.04
2.0 - 2.5	2.86
3.5 - 4.5	6.53

Settleable solids and turbidity can damage the aquatic habitat and interfere with biotic productivity. The problem is tremendous and threatens many of the choice recreational headwater streams. Suspensoids of industrial origin are identifiable and usually controllable. Immediate corrective measures should be not only encouraged but required where necessary to preserve threatened waters or reclaim lost ones.

REFERENCES

- Anon. 1956a. Aquatic Life Water Quality Criteria, Second Program Report. Sew. and Indust. Wastes, 28:678-690.
- Anon. 1956b. Coal River gets 15,000 bass. W. Virginia Conservation 19:28.
- Anon. 1954. Central Missouri River Water Quality Investigation, August 1952 - December 1953. U.S.P.H.S., Kansas City, Mo., 72 pages.
- Anon. 1955. National Survey of Fishing and Hunting. F.W. L.S. Circular 44, 50 pages.
- Anon. 1958. Statistical abstract of the United States. U.S. Department of Commerce, Supt. of Documents, Table No. 915, page 702.
- Bartsch, A. F. and W.S. Churchill. 1949. Biotic responses to stream pollution during artificial stream reaeration. Limnology, Water Supply and Waste Disposal: 33-48, A.A.A.S. Publ.
- Bartsch, A. F. 1954. Bottom and plankton conditions in the Potomac River in the Washington Metropolitan Area. Section III, A Report on Water Pollution in the Washington Metropolitan Area, Interstate Comm. on the Potomac River Basin, 1-24.

- Bartsch, A. F. 1953. Unpublished data.
- Bennett, G. W., D. H. Thompson, and S. A. Parr. 1940. Lake Management Reports. 4. A second year of fisheries investigations at Fork Lake, 1939. Ill. Nat. Hist. Sur., Biol. Notes No. 4:1-24.
- Birge, E. A. and C. Juday. 1929. Transmission of solar radiation by waters of the inland lakes. Trans. Wis. Acad. Sci. Arts Letters 24:509-580.
- Birge, E. A. and C. Juday. 1930. A second report on solar radiation and inland lakes. Trans. Wis. Acad. Sci. Arts Letters 25:285-335.
- Birge, E. A. and C. Juday. 1931. A third report on solar radiation and inland lakes. Trans. Wis. Acad. Sci. Arts Letters 26:383-425.
- Birge, E. A. and C. Juday. 1932. Solar radiation and inland lakes. Fourth Report. Observations of 1931. Trans. Wis. Acad. Sci. Arts Letters 27:523-562.
- Bowers, R. R. 1955. They are giving you back a river. W. Virginia Conservation 19:10-13.
- Chandler, D. E. 1942. Limnological studies of Western Lake Erie. II. Light penetration and its relation to turbidity. Ecology 23:41-52.
- Cole, A. E. 1935. Water pollution studies in Wisconsin. Effects of industrial (pulp and paper mill) wastes on fish. Sew. Wks. Jour. 7:280-302.
- Dymond and Delaporte. 1952. Pollution of the Spanish River. Research Rept. No. 25, Ontario Dept. of Lands and Forests, Div. of Research, 106 pages.
- Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29.
- Ellis, M. M. 1944. Water purity standards for fresh-water fishes. F.W.L.S. Spec. Sci. Rept. No. 2.
- Everhart, W. H., J. E. Watson, and R. E. Cutting. 1955. Penobscot River Salmon restoration. Maine Atlantic Salmon Comm. and Dept. of Inland Fish and Game. 14 pages.
- Kemp, H. A. 1949. Soils pollution in the Potomac River Basin. Interstate Comm. on Potomac R. Basin. 21 pages.
- Newcombe, C. L. 1951. Water wealth lost by silt pollution. Soil Conservation Magazine 16:4 pages.
- Shapovalov, R. 1937. Experiments in hatching steelhead eggs in gravel. Calif. Fish and Game 23:208-214.
- Shaw, P. A. and J. A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. Calif. Fish and Game 29:29-41.
- Smith, O. R. 1939. Placer mining silt and its relation to salmon and trout on the Pacific Coast. Trans. Amer. Fish. Soc. 69:225-230.
- Tebo, L. B. Jr. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the Southern Appalachians. Prog. Fish. Cult. 17:64-70.
- Van Horn, W. M. 1953. Progress in stream improvement. Paper Industry, March, April, June, 1953. 8 pages.
- Wallen, I. E. 1951. The direct effect of turbidity on fishes. Bull. Okla. Agric. and Mech. Coll. Biol. Ser. 2, Vol. 48:1-27.
- Ward, H. B. 1938a. Placer mining on the Rogue River, Oregon, in its relation to the fish and fishing in that stream. State of Oregon, Dept. of Geology and Mineral Indust., No. 10, 31 pages.
- Ward, H. B. 1938b. Placer mining and the anadromous fish of the Rogue River. Science 88:441-443.
- Wilson, J. N. 1953. Personal communication.

ENVIRONMENTAL REQUIREMENTS OF OYSTERS IN RELATION TO POLLUTION

Paul S. Galtsoff, Bureau of Commercial Fisheries, Woods Hole, Massachusetts

ABSTRACT

Oysters tolerate great changes in salinity and temperature. Highly perceptive organs of chemical sense and ability to remain closed for many days are adaptations to the instability of their environment.

The ten major factors of oyster environment may be grouped into two classes of favorable or positive and destructive or negative factors. The positive factors are: character of bottom, temperature, salinity, water movements and food. Only two of these factors, namely, the character of bottom and food, are directly affected by pollution.

Physical characteristics of bottom are changed by the deposition of sludge, by increased sedimentation and by settling of precipitates.

Normal food chain is adversely affected by industrial wastes which destroy many forms utilized as food by adult and larval oysters. Enrichment of water by organic waste, devoid of toxic ingredients, may upset the balance of nutrients and in this way stimulate the growth of useless and harmful forms. Examples of such conditions are found in Great South Bay, Long Island, New York where pollution from duck farms overstimulates the growth of *Chlorella*-like algae, and in Shelton Bay, Washington, where the red liquor, rich in carbohydrates, induces heavy fouling of Olympia oyster beds by filamentous *Melosira*.

Temperature, salinity and water movements are affected by pollution only in rare and unusual circumstances.

The five negative factors are: natural sedimentation,

changes associated with human activities, competition, predation, and disease. The last three factors are not seriously affected by pollution.

Sedimentation is in general inimical to the life of the oyster. The rate of deposition of suspended matter is increased by pollution because all wastes contain a relatively high percentage of solids, either in solution or in suspension. Toxic materials may be carried by tides and deposited at considerable distances from the place of discharge. Even nontoxic materials, such as sawdust, dumped indiscriminately into coastal waters, may irreparably spoil oyster bottoms and render them uninhabitable by other shellfish.

Artificial changes produced in estuaries by dredging, construction of dams and flood-water barriers, deposition of spoil materials and discharge of various wastes constitute the principal negative factor of oyster environment. Changes in the configuration of bottom alter the pattern of currents which, in turn, may affect the distribution and setting of larvae. More serious, however, is the discharge of toxic substances. They reduce the rate of feeding and respiration; interfere with the calcium and carbohydrate metabolism; affect the locking mechanism of the adductor muscle; and reduce the reproductive capacity by impeding gonad development, preventing fertilization, or by killing the larvae.

Conditions resulting from the combined action of several factors of natural environment affected by pollution are more serious than the adverse action of a single factor observed in the laboratory.

Under natural conditions, unspoiled by human activities, the organisms of inshore waters live in an equilibrium with their environment. This adjustment is the result of thousands of years of adaptation and natural selection. It can be easily upset by various changes associated with the growth of human population and industrialization of coastal areas. The most pronounced effects are caused by the discharge into water of foreign materials normally not present in it or by the addition of an excess of some of the normal components of sea water. All these changes to a greater or lesser degree alter the normal conditions of the environment and contribute to the pollution of coastal waters.

There is no "good" or "harmless" pollution.

All types of pollution are harmful to marine populations, the differences being only in the degree of their effects which may be slight and remain undetected for a long time or may be strong enough to cause almost immediate destruction of certain species. Useful enrichment of sea water by organic matter and nutrient salts can be achieved only by controlled and balanced fertilization. Pollution by domestic sewage and industrial wastes which may contain carbohydrates, phosphates and nitrates fail to produce desirable results because neither the rate of discharge nor the concentrations of nutrients are controlled. The resulting imbalance of nutrients may enhance reproduction of useless and sometime harmful microorganisms which replace the useful forms.

DIRECT AND INDIRECT EFFECTS OF POLLUTION

The changes in the environment often have direct effects on the organisms; they produce mortalities; reduce the rate of survival of larval and juvenile forms; and affect the palatability or usefulness of marine animals for human consumption. The latter instances are of particular importance to shellfish industry, since in polluted waters the bivalve mollusks become contaminated or may lose a considerable portion of the weight of their flesh. Such changes commonly occur among oysters grown in waters affected by domestic and industrial wastes.

Indirect effects of pollution are less apparent but may be equally destructive. The normal ecological environment may be so changed by pollution that some plankton organisms, most useful as food of shellfish, disappear and are replaced by luxurious growth of microorganisms not only useless as food but even harmful to water-filtering mollusks. These changes in the environment frequently remain undetected because of the difficulties involved in observing them and also because of our inadequate knowledge of food requirement of commercial mollusks at different stages of their life cycles. Indirect effects of pollution constitute, however, serious dangers to the survival of shellfish populations and are probably some of the major causes of frequent failures of their reproduction.

INSTABILITY OF OYSTER ENVIRONMENT

Oysters are limited in their distribution to a narrow zone of coastal sea bottom. Inhabiting the estuaries, tidal rivers and bays they exist under rather unstable conditions. The major factors of their environment, such as temperature, salinity and water movements, are subject to daily, seasonal and sometime irregular and sudden changes. In order to survive under such conditions the species must have developed great tolerance and adaptability to these changes. The oyster possesses these qualifications. It tolerates extensive changes in temperature from 0° C. to about 35° C. It can adjust itself to wide fluctuations in the salinities from nearly fresh water to the concentration of salts of more than 3.5 percent. Furthermore, by using the locking mechanism of its adductor muscle the oyster is able to hermetically seal the valves and survive without food or water for about three weeks. Species of shellfish which lack

this type of muscular mechanism, for instance the pearl oysters, rapidly succumb to unfavorable conditions in which the edible oysters survive without harm.

TEN MAJOR FACTORS OF THE ENVIRONMENT

The factors of the environment which control the life of oyster populations can be grouped in two large classes: (a) those which are indispensable for the existence and welfare of the population, and (b) those of destructive nature which interfere with growth, reproduction and survival of species. The first group comprises the positive factors of the environment; the second one consists of negative ones. The prosperity of an oyster population is affected by the interaction of all positive and negative factors. The effect of a single factor of the environment can be evaluated by studying the manner in which it controls vital functions of the organism and by determining the optimal conditions under which it operates. For instance, since oysters cease feeding at temperatures about 8° C. and lower, the value of a temperature factor of a given estuary may be expressed as percentage of the number of days the oysters may feed in the locality. Other factors may be evaluated in a similar manner.

Positive factors

The positive factors of the environment are as follows: character of bottom, temperature, salinity, water movements and food. Pollution of water may have direct effects on bottom, salinity of water and food. Temperature and water movements are not affected by pollution except in some unusual and rare circumstances when hot effluents are discharged onto inshore waters or when the rate of discharge is so great that it interferes with the normal pattern of circulation. Such instances may be encountered only in very small bodies of water but even there the adverse effects are rapidly dissipated.

The effect of pollution on physical and chemical characteristics of bottom is fairly common and is frequently well pronounced. Both domestic sewage and industrial waste contain substantial quantities of solids which are rapidly settled in sea water and cover the oyster bottoms. Sediments derived from domestic sewage form sticky, soft sludge of high organic content. Its accumulation on bottom covers and

smothers the oysters killing them or rednering them unsuitable for human consumption. If pollution continues unabated for many years the hard or semihard bottom, suitable for cultivation, is converted into soft mud saturated with hydrogen sulfide and entirely unsuitable for the growing of oysters. Highly polluted harbors of the Atlantic Coast may be cited as typical illustrations of these conditions. They are found, for instance, in Jamaica Bay, New York, in Bridgeport harbor and New Haven harbor, Connecticut, in upper parts of Narragansett Bay, in Boston Bay, in Great Bay, New Hampshire and in many other places of our coast. The destruction of formerly productive oyster bottoms by the deposition of sludge or sediments may persist for several decades after the pollution had been stopped. A striking illustration of such a case is found in the formerly productive area in Damariscotta River, Maine, known as Salt Pond and located above the Newcastle-Damariscotta bridge. The bottom of this pond was destroyed by sawdust and trash dumped long ago by the lumber mills. Although the local mills stopped functioning at the turn of the century, the bottom of the bay in 1940 was still covered with a layer of decomposing sawdust 3-4 feet thick. No oysters, of course, could exist in such conditions, but a few live oyster drills were present at the time of my visit.

Changes in the proportions of the chemical constituents of sea water under certain conditions encourage the growth of algae to an extent which interferes with the life of the mollusks. This condition was reported by several investigators who studied the pulp mill pollution in Shelton Bay, Washington. The red liquor, a waste product of sulfite process of pulp making, was discharged at the head of the bay in the vicinity of oyster beds of Olympia oyster, *Ostrea lurida*. High organic content of the liquor stimulated the growth of the filamentous diatom, *Melosira*, which covered the entire bed with a thick carpet of algal growth. Soon after the pollution by red liquor had been stopped, the *Melosira* disappeared in a short time, only to reappear when the discharge of red liquor was resumed.

The organic matter of the domestic sewage encourages the growth of green algae *Ulva* and *Enteromorpha*. These species do not interfere with the growth of oysters but their presence serves as an indication of the possible contamination of water.

Pollution has a pronounced effect on the food cycle in sea water. The entire balance of nutrients in sea water may be upset and water becomes overfertilized by nitrogen and phosphorous contained in waste material. This condition was created in Moriches Bay in Long Island, New York, by an unbalanced overfertilization from the drainage of duck farms.

Exceptionally dense blooms of a unicellular alga related to *Chlorella* appeared in the bay and greatly interfered with the feeding, growth and reproduction of shellfish. These blooms were correlated to the increase in total nitrogen to 90-200 microgram atoms per liter and phosphorous to 20-25 microgram atoms per liter (Redfield 1952). The excess of nitrogen, which constitutes the limiting factor for algal growth, was traced to the discharge of drain waters polluted with duck excreta which contained large quantities of uric acid. This situation was greatly improved by the widening of the channel leading to the ocean and improved circulation in the bay.

Negative Factors

The major negative or destructive factors of oyster environment are sedimentation, changes caused by man's activities, competition, predation and disease. The last three factors, i.e., competition, predation and disease are not seriously affected by pollution.

Sedimentation over the oyster beds is materially increased if the pollutant discharged into inshore waters contains large quantities of solids in suspension. The changes in the physical characteristic of bottom sediments may be so great as to render the grounds unsuitable for oyster population, as has been already mentioned in the discussion of the character of the bottom. In tidal rivers and in the estuaries with strong tidal currents the suspended material may be carried a considerable distance from the place of discharge. In bodies of water of this type the scour areas, where bottom materials are being washed away, alternate with the areas where sediments are deposited. The deleterious action of a pollutant is more pronounced in the latter areas than in the first ones, and consequently the overall effects of pollution may be greater at a certain distance from the place of discharge than in its immediate vicinity. Oyster bottoms of tidal rivers within the areas of industrial developments are particularly vulnerable to such

damages.

In many instances careless disposal of vegetable waste by canneries creates unhealthy conditions, which, however, being conspicuous, provoke immediate protests from property owners and are usually rapidly corrected. The principal effect of that type of pollution is the reduction of oxygen content of water and the accumulation of decomposing matter on the bottom.

The discharge of industrial waste containing chemicals which form precipitates in sea water presents a more complex condition. An example of such a case is the disposal of copperas by certain pigment plants. The ferrous sulfate has no commercial value and is discarded as waste after titanium dioxide, a white paint pigment, is extracted from the mineral ilmenite (ferrous titanite, FeTiO_3) by sulfuric acid. In some of the plants the rate of disposal of waste byproduct exceeds 150 tons per day. In sea water the dissolved ferrous sulfate is rapidly hydrolyzed lowering the pH and forming basic ferrous salts. The ferrous ion is oxidized to ferric iron, thus reducing the oxygen content of water. The insoluble yellow-brown colloidal precipitate of $\text{Fe}(\text{OH})_2$ settles on bottom as a flocculent sediment. Flocculation and settling may take place at considerable distance from the discharge depending on salinity gradients of the place and its hydrography. My experiments show that copperas is not toxic to adult oysters. The precipitate is absorbed by blood cells on the surface of the gills, and iron particles carried out through the mesenchyme are gradually discarded by the epithelium of the mantle.

The flocculent sediment in water affects the plankton. It adheres to the long spines of *Chaetoceros* and other diatoms and is entangled between the legs of plankton crustacea. In extreme cases the precipitate acts as a coagulant which carries the plankton to the bottom.

The effect of copperas on oyster larvae has not been studied but is probably harmful since the salt contains considerable quantities of copper which is extremely toxic to them.

Precipitation of hydroxides of other heavy metals also occurs when their salts are dumped in sea water. It is known that copper, mercury, lead, and arsenic absorbed by oysters and other bivalves are stored in their tissues and render them unsuitable for human consumption (Hunter

and Harrison 1928). It is, of course, a common knowledge that excessive amount of copper is the cause of green discoloration of oysters which renders them unmarketable. These oysters are frequently found in the waters contaminated with industrial wastes of various metal works.

Sedimentation is indirectly involved in oil pollution of waters heavily loaded with silt. Oil is readily adsorbed by clay particles which flocculate and sink to the bottom. In this manner a film of oil disappears from the surface of a polluted area and is deposited on bottom at a distance of several miles from the source of pollution. Strong wave action may release the oil from bottom sediment. The film suddenly reappears on the surface of water and is carried farther by the tide. Such cases of pollution of oyster bottoms have been seen at a distance of several miles from the place of original spillage of oil. Shellfish in contact with minute amounts of oil acquire an unpleasant "oily" flavor and are unmarketable.

Dredging of channels, construction of piers, bridges, draining of marsh areas and similar activities frequently are harmful to oyster grounds. Dredging may adversely affect the oyster bottoms in three different ways: (1) by changing the pattern of circulation, (2) by smothering the grounds with sediments, and (3) by releasing toxic substances entrapped in the deeper layers of mud. Change in the pattern of circulation is often responsible for carrying the oyster larvae away from the places of attachment and the resulting loss of commercial set.

The deposition of sediments stirred up by dredging and coastal construction is usually limited to a zone adjacent to the sites of operations. Dredging may, however, release the toxic substances accumulated for years in the mud of harbors and bays near the industrial cities. This difficulty can be usually foreseen. The release of H_2S by dredging of swamps and estuaries occurs very often but is rarely destructive to oysters, although the escaping gas may spoil the lead paint commonly used on boats and buildings.

Discharge of untreated domestic waste is the principal destructive factor of oyster environment. Its overall effect on sea bottom results in a decrease of the number of species found in a polluted area. This general rule is illustrated by the observations of Reish (1955) on relation

of polychaetous annelids to harbor pollution which show the gradual decrease in the number of the species in the polluted waters and their replacement by more tolerant forms. These changes, by themselves, do not affect the populations of oysters. It is of interest to note, however, that a species of *Polydora*, a mud worm which indirectly affects the oyster, was found by Reish to be predominating in a semihealthy bottom area in Los Angeles and Long Beach.

The major effect of industrial wastes on oysters consists in the reduction of the rate of various physiological functions. The principal function of the oyster is the ventilation of the gills. The current produced by the beating of the ciliated cells of gill epithelium is essential for feeding, respiration, and discharge of excreta. Under normal conditions and at temperatures about 60° to 70° F. the oysters remain open on the average of about 20-22 hours a day. The presence of pollutants reduces the number of hours in proportion to the concentration of toxic substances in the water. If the number of hours closed is plotted against the log of concentration the relationship can be expressed by a straight line as shown in Figure 1. Toxic substances affect the frequency of ciliary beat and interfere with the coordination of the ciliary motion with the result that the pumping capacity of the gills is reduced. The reduction is proportional to the concentration of the physiologically active materials and can be expressed by an exponential curve similar to that shown in Figure 1. This type of relationship was described in studies dealing with the pollution of oyster beds by red and black liquor and by water soluble components of crude oil (Galtsoff 1931; Galtsoff, et al 1947; Chipman and Galtsoff 1949). The results of the latter observations are in agreement with the data reported by other investigators (Seydel 1913 and Veselov 1948) who demonstrated the toxicity of crude oil to fishes.

Slow poisoning of oysters by continuous exposure to low concentrations of toxic material results in poor quality oyster meat and in the loss of their reproductive capacity. The presence of dilute amounts of sulfite (red) liquor in waters of Oakland Bay and adjacent areas of Puget Sound was found to be correlated with the poor quality, lack of reproduction and mortality of Olympia oysters (McKernan, et al 1949). Comparative studies of the glycogen cycles in the two rivers emptying side by side in the Chesapeake Bay showed that oysters in the polluted

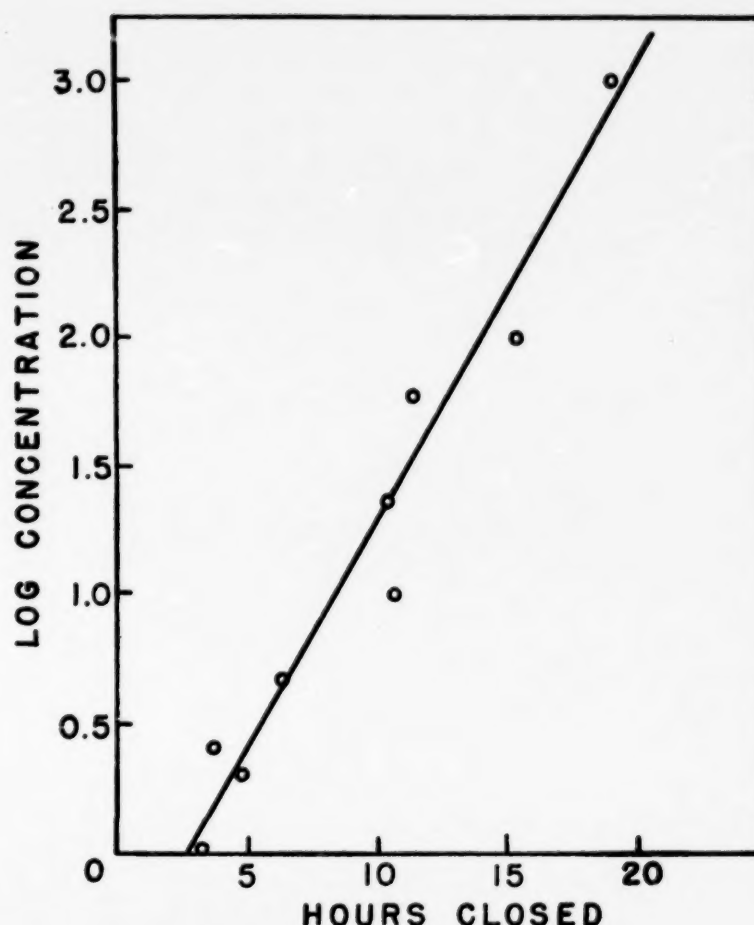


Figure 1. Effect of increased concentrations of an extract of crude oil in sea water on the number of hours the oyster remains closed.

waters of York River, Virginia, were poorer in glycogen content than the oysters from the adjacent Piankatank River which was not affected by pollution (Galtsoff, et al 1947). Furthermore, the toxic substances in water, as a rule, reduce the length of time the oysters feed, thus diminishing the amount of food they consume.

There is evidence accumulated in the laboratories of the Bureau of Commercial Fisheries that oyster larvae are extraordinarily susceptible to minute concentration of copper and DDT. It was reported that a concentration of one part of DDT in forty million used in spray is sufficient to destroy the larvae.

Accumulation of toxic waste in sea water may reach the concentration which is lethal to adult, juvenile and larval oysters. The death of the adult and young oysters usually attracts immediate attention of the oystermen but the destruction of larvae remains unnoticed by

laymen. Many instances of the failure of oysters to set can be traced to direct or indirect effects of pollution. This situation exists, for instance, in the polluted area of Fall River, Massachusetts, where the populations of oyster larvae are sometimes destroyed by occasional discharges of toxic wastes from numerous industrial plants situated on the banks of the river.

There is no evidence that competition, predation and diseases are aggravated by pollution. It is reasonable to expect that the resistance of oysters to infection may be weakened by toxic substances in water, but concrete evidence that this is the case is lacking.

COMBINED EFFECTS OF ENVIRONMENTAL FACTORS

So far we have considered the effects of various types of pollution in their relation to a single factor of the environment. This artificial condition, attained only under strictly controlled laboratory experimentation, does not exist in nature. Factors of the environment do not operate singly but always act jointly. One serious weakness of many ecological studies of marine populations is the tendency to correlate the results of biological observations with one or possibly two selected factors of the environment, such as temperature, salinity or hydrographic conditions. In reality, a given factor can exert its effect only in conjunction with other factors. For example, in the studies of the effects of pollution on an oyster population it is impossible to separate the effect of chemical changes of the environment, produced by the pollutant, from the transfer of the pollutant by the movements of water, and from the effects of pollutant on food chain. Likewise, the changes in character of bottom brought about by pollution cannot be segregated from the direct effects of pollutants on the chemistry of the water, oxygen contents, changes in pH, etc. Combined action of several factors may produce greater effect than one caused by a single adverse condition. It has been

demonstrated in ecological literature that the results of the joint action of several factors may be different from the effect of the individual factor (Rübel 1935). This general principle is fully applicable to the effects of water pollution on aquatic animals.

Field experiments on mortalities of oysters conducted by Günter (1955) in Texas may serve as an illustration of this principle. He found that the rate of mortality of oysters, not due to predation, at stations where in June-July the salinity of water was high, varying from 35-36 parts per thousand, was about five times greater than the mortality at the other stations located in the areas of lower salinities. Oysters used in Günter's tests were taken from their natural habitat in Texas waters. There was no indication that the specimens which were placed at stations of higher salinity and suffered higher mortality were in any respect different from other oysters kept in water of low salinity. There was no difference between the two groups in the degree of infestation or in the incidence of disease.

Environmental conditions are often responsible for the differences in the mortality of oysters subjected to the same type of pollution. This can be frequently observed among the oysters living in the marginal zones of their habitat, for instance, in the waters of greatly reduced salinities in the upper reaches of tidal rivers, in the upper part of Mobile Bay, Alabama, in Galveston Bay and in Copano Bay, Texas.

It is more difficult to study a joint action of several conditions of the environment than to determine the effect of a single factor. With proper technique and equipment the difficulty can be overcome. Investigations conducted from an ecological point of view should take into consideration the combined action of all positive and negative factors. This approach appears to be more promising in solving the problems of pollution of estuarine waters.

REFERENCES

Chipman, Walter A. and Paul S. Galtsoff. 1949. Effect of oil mixed with carbonized sand on aquatic animals. Fish and Wildlife Ser., Spec. Sci. Rept. Fish. No. 1: 1-53, 8 pl.

Galtsoff, Paul S. 1931. The effect of sulfite waste liquor on the rate of feeding of *Ostrea lurida* and *Ostrea gigas*. Bull. Bur. Fish. 47: 162-167.

Galtsoff, Paul S., Walter A. Chipman Jr., James B. Engle and Howard N. Calderwood, 1947. Ecological and physiological studies of the effect of sulfate pulp mill wastes on oysters in the York River, Virginia. Fish. Bull. Fish and Wildlife Ser. 51: 58-186.

Günter, Gordon. 1955. Mortality of oysters and abundance

of certain associates as related to salinity. Ecology 36: 601-605.

Hunter, Albert C. and Channing W. Harrison. 1928. Bacteriology and chemistry of oysters with special reference to regulatory control of production, handling, and shipment. U. S. Dept. Agric., Tech. Bull. 64: 75 pp. Washington D. C.

McKernan, Donald L.; Vance Tartar and Roger Tollefson. 1949. An investigation of the decline of the native oyster industry of the State of Washington, with special reference to the effects of sulfite pulp mill waste on the Olympia oyster (*Ostrea lurida*). Dept. Fish., State of Washington, Biol. Rept. 49A: 115-165.

Olson, R. A.; H. F. Brust and Willis L. Tressler. 1941. Studies of the effects of industrial pollution in the lower Patapsco River area. Chesapeake Biol. Lab., Solomons, Maryland, Publ. 43: 40 pp.

Refield, Alfred C. 1952. Report to the towns of Brookhaven

and Islip, New York on the hydrography of Great South Bay and Moriches Bay. Woods Hole Oceanogr. Inst., 79 pp.

Reish, Donald J. 1955. The relation of polychaetous annelids to harbor pollution. Public Health Rept., Public Health Ser. 70(12): 1168-1174.

-----; 1957. The relationship of the polychaetous annelid *Capitella capitata* (Fabricius) to waste discharge of biological origin. In Biol. Problems in Water Pollution, C. M. Tarzwell, Editor. U. S. Public Health Ser.

Rübel, Edward. 1935. The replaceability of ecological factors and the law of the minimum. Ecology 16: 336-341.

Seydel, Emil. 1913. Ueber die Wirkung von Mineralölen auf Fischwasser. Mitteilungen d. Fisherei-Vereins für Provinz Brandenburg 5(3): 26-28.

Veselov, E.A. 1948. Effect of crude oil pollution on fishes. Rybnoe Khoziaistvo 12: 21-22. (In Russian.)

A CONSERVATIONIST'S VIEWS ON THE PRACTICAL APPLICATION OF BIOLOGICAL FINDINGS

Ernest Swift, Executive Director, National Wildlife Federation, Washington, D. C.

To keep the record straight, let me make it clear that I am not qualified to speak as a scientist or biologist on the subject under discussion. Therefore, I must talk on those aspects with which I am familiar and within the realm of my experience as they apply to the subject.

I believe it has been proven that in any present-day advancement where the ecological factors of nature are involved, there must be coordination and team work.

To a considerable degree, my experience has been in the field of administration; although not entirely.

Everyone on the team must have certain talents and this is no less true of a successful administrator.

A scientist sitting at his desk views a problem within certain limitations; a supervisor of research may appreciate the specifics which confront the scientist but has additional issues that confront him; the over-all administrator will not only have a knowledge and an appreciation of the questions his helpers are attempting to answer but will have a substantial number to add which he must solve himself.

Human nature being what it is, it is only natural that the specialist sometimes feels that the administrator fails to understand the problems he faces and that he is hard-hearted and unappreciative, and sometimes, even, just plain dumb; the other side of the page is that the administrator fondly wishes that the specialist could appreciate the multiplicity of problems he is constantly faced with.

I believe that I know some of the important qualifications of the ideal administrator. If he lacks them, the specialist will fail or his work put to no definitive use; however, there should

be an appreciation on both sides.

An administrator must have: 1) a basic understanding of the objectives he is trying to reach; 2) a sympathetic understanding toward the people charged with specific responsibilities, whether fact-finding or other types of job accomplishments; 3) a judicial approach to weighing of evidence, whether it is factual or simply an opinion; 4) the ability to extend this judicial approach in coordinating the efforts of persons and groups, who range from those with highly specialized interests, to those with a public interest or those whose interests may be antagonistic; 5) the ability to disarm opposition and at the same time have the determination to carry through to reach the desired objective; 6) the imagination to see over the next range of hills, to envision unforeseen problems and be prepared for them; 7) the patience and fortitude to deal with all the cross-currents of public interest and personal piques that tend to defeat programs.

In other words, the administrator also is a specialist in his own peculiar field. His specialty is in developing a well-coordinated program, one which makes the best possible use of talents possessed by other specialists.

This meeting is about water -- basically its uses and abuses -- and in great part how to overcome the abuses. If it is not already, it will become our biggest conservation problem. As the situation becomes worse we will hear a great hue and cry from many sources and many interests: "Why hasn't something been done about it?" In great part much of this criticism will result because certain interests did not get their pound of flesh and because they feel their position was compromised, or so they will contend.

Although specialists may become cynical, administrators have far more justification to indulge in this human attitude, especially if they

are attempting to give a fair evaluation to all users and all interests.

To the administrator this whole field of resource management has a far broader scope than the ecological relation between plants, animals, soil and water; for in its broader sense it is concerned with industry, standards of living, education, markets, legislation, courts, and through it all those aspects of life--economic and esthetic and recreational--which people enjoy. Some consider the management of resources more of an art than a science, but certainly it is a meeting ground for many sciences in the biological, engineering and social fields.

As we are all well aware, there are those who place only a dollar value on all resources. The dollar is their standard of measurement, and if it is not readily apparent, they see no value whatsoever.

Here lies our basic difficulty--lack of common agreement as to values. Because of this lack of agreement we have a multiplicity of interests opposing one another. For this reason the entire conservation concept is hard to define, it is almost impossible to establish a base line; there is no common denominator for all interests or all intellects.

Let me put it another way. Some groups with narrow interests do not have the intellect to appreciate the vast ramifications involved. Others with narrow interests may have the intellectual capacity to visualize the broad scope of resource management, but in their greed they refuse to recognize it.

The sanctity of the almighty dollar collides with the sanctity of values which cannot be measured by the dollar standard.

One person viewing a sunset across an expanse of river feels the ethereal majesty of unknown powers too tremendous and too vague to fully comprehend; another person may be only conscious that it is daylight, but laments the number of kilowatts being wasted because the river has not been dammed. One person wishes to spend a few pleasurable hours fishing and possibly enjoying the bordering woodland beauty; another wishes to use the river as a sewer for his industrial plant.

In simple terms this is the crux of assessing the different values which a river affords. The unanswered question is how do we compromise between these values; how much can we give and how far can we go? The very force of human strife reflected in the different values dictates that under many situations compromise will be forced upon all points of view.

As an administrator I have found that compromise is an essential and realistic approach in saving in part some of the values I hold to be important.

Several years ago I listened to a discussion on what position the American Fisheries Society should take regarding the numerous dams under consideration on the Columbia river and its tributaries, especially the Snake, the Salmon, Imnaha and Clearwater. Everyone agreed that the multiplicity of dams posed a serious problem in sustaining the salmon run. Finally one young biologist got up and made an impassioned plea to oppose them all. He maintained that any other position was a compromise of principles.

Already the Army Engineers, public power interests and private industry had built dams and it was as certain as God made little apples that more were going to be built. To simply oppose all dams on the Columbia and make no effort to develop studies to minimize losses and destruction would not save the salmon.

Standing on principle in that instance would have been a very hollow victory--if a victory at all. This is what I mean by being realistic; certainly a judgment factor is involved as well as the matter of principle.

Here again, we come back to the question I raised on defining conservation principles. How do we define principles, what common denominator can be used? Principles are like honesty, whatever one wants to make of them. To a great extent people--the general mill run of them--condition their principles to what is immediately advantageous to them, especially when a profit is involved.

I have some quirks of philosophy which seem strange and unnatural to some people. Everyday we hear or read that the conservation effort is justified as a benefit to mankind. So the need for conservation is based on the premise that the human being is something special in the

general scheme of this universe.

Actually, that philosophy is nothing more than self-interest--a self-determined conclusion or premise created by the human animal even before the dawn of history when he was learning to walk on his hind legs, and it has been nurtured through thousands of years under the assumption that man has some special importance.

In other words, the human being has made up his mind that he is something special--it's a Jehovah complex of a sort--and no one is going to change his mind, in spite of the fact that no impartial adjudication has ever been submitted on the issue.

I am one of the species, but I often wonder just how special and important we really are considering the general scheme of things. We are naturally aggressive, predatory and consistently hypocritical. We are always attempting to justify these attributes.

We would be more honest if we would look at ourselves in the mirror and admit that survival is based on exploitation and predation. We justify our own predation, but we kill other animals for doing what we do. However, there will be no survival unless exploitation and predation are restrained. There will be no survival if resources are not given careful husbandry.

This thing we hug to our breasts and call civilization has other hypocritical aspects.

The Indian, on killing a buffalo, thrust his knife into its paunch, pulled out the bloody quivering liver and ate it raw. Therefore, he was a savage and a barbarian. What do we do? We hire someone to take a steer to the slaughter house, and after it is killed we have the liver brought to our back door so that the householder, if he is anemic, can eat it raw.

The Indian killed to live--we kill to live. We attempt to justify our killings by circumscribing them with certain phoney refinements. We envelope ourselves with an endless number of sophisticated deceits, and call it civilization.

We are constantly relating the use of resources--water, in this instance--to the over-worked term "standard of living". I maintain this to be a vague and ambiguous term, but to most people its common usage means material gad-

gets, luxuries, few responsibilities, short hours, and fringe benefits. It has lost all connotation of moral, esthetic and intellectual standards.

Here, again, I am right back where I started, what common denominator can be used to define living standards? To the great mass of people it is impossible to apply a definition of conservation principles other than that of self-interest and living standards.

If high ethical principles and the real meaning of living standards cannot be properly interpreted by people, how are we going to convince people that resources have other values than utilizing them for the cheap, artificial gee-gaws invented to make people both intellectually and physically slothful, lazy and wasteful. The makers of sporting goods are now defeating the therapy of the out-of-doors with all their make-it-easy gadgets. The more civilized and cramped for space we become, the more we need the therapy of the out-of-doors, but some people cannot comprehend how the Sermon on the Mount, or the Gettysburg Address came into existence prior to indoor plumbing and electric lights.

I cannot over-emphasize the serious problems facing the nation in connection with water--the subject for this meeting. Increasing human populations, plus continued new inventions, many of them for luxury use, brings this about. When people carried water from the well into the house, they neither used nor wasted as much water as today's household. When they walked out back to a Chick Sales, several gallons of water did not go down the sewer.

If water is ever discussed in our American households, it is because of the water bill and not from the standpoint of wasting a resource.

Today in many states, there is a deadly struggle going on between the various water users; particularly whether there will be any left for recreation, and if there is, whether it will be usable or so polluted that it becomes a menace to aquatic and human life.

To date, our misuse of water, our most vital resource, is a national scandal. In this legislative year there are bills before Congress and the legislative bodies of every state--bills by the bale--to divide up water among the many users, but few of them are really conservation bills.

A little aside from the present discussion,

but still relating to water, the sportsmen are now going to pay three dollars for a duck stamp to help preserve some of the vanishing wetlands in the United States, especially in the prairie states where waterfowl breed. At the same time, you are being taxed to subsidize farmers to dry up the very land the duck stamp is attempting to save.

Two Federal bureaus are competing: The Department of Interior to save the wetlands, and the Department of Agriculture to destroy them.

We promote conservation in the hope that the human race can survive and at the same time derive certain measures of enjoyment. That is the objective. Conservation is a vast and complicated process of husbandry and rationing. How are we going to set standards of values for all interests? That is still an unanswered question. To date, I believe the people of America do not really want conservation within the true meaning of the word.

I have imparted my philosophies and have, as I promised, stayed within the realm of my experience as it relates to the subject; but let us look for a brief moment at the practical application of biological findings.

All biological research is interesting. Not all, however, is practical. Knowledge of the hummingbird's wing-beat rate is interesting but the practical application of this information escapes me. The point is that all biological research should have a planned, practical objective, one which fits in with a definite need to solve a particular problem. This approach can be made without compromising pure science

with bias or prejudice. We also say this with a full awareness that a relatively small percentage of any research effort will "pay off" with revolutionary concrete results.

We need to know more about eliminating trash fish through selective chemicals; the effect of chemical pesticides and detergents upon aquatic organisms; and practical fish production management methods on large lakes. There are many other practical possibilities.

Most of all, however, conservationists would like water engineers and biologists to give more attention to problems of pollution and its elimination and less research emphasis on the question of how great a load of pollution a stream can safely handle. This approach also may require a change in the philosophy of some individuals.

There is little need to document the need for clean water for a variety of useful purposes. Everyone here also is aware of the recent tremendous upsurge in public interest about water-involved outdoor recreations such as fishing, hunting, swimming, water-skiing, boating and so on. In conclusion, however, I would like to say that sportsmen-conservationists everywhere are vitally concerned about clean water and associated biological problems and you will find them among the strongest supporters of your programs if called upon. They are available on local, regional and national levels.

This is the way useful research looks from the chair of one administrator.

WHAT DOES THE SANITARY ENGINEER EXPECT OF THE BIOLOGIST IN THE SOLUTION OF WATER POLLUTION PROBLEMS?

Erman A. Pearson, Associate Professor - Sanitary Engineering,
University of California, Berkeley

The evaluation and solution of water pollution problems is becoming increasingly complex for several reasons. First, in many instances today, water pollution does not constitute deterioration of the aquatic or marine environment so obvious that it can be detected with the eye or nose by the layman as well as the scientist. Secondly, there is an increasing quantity and variety of materials being discharged to the environment. Thirdly, there are many physical and man-made factors that affect the general condition of the environment other than waste discharge.

The effective conservation and intelligent use of our natural resources should not allow gross deterioration of the nation's water resources. The complex potential effects that waste discharges may have on our water resources and associated beneficial uses necessitates that methodology be developed and evaluated for assessing biological effects or damage resulting from waste discharge.

PUBLIC HEALTH PROBLEM ANALOGY

The problem associated with the solution of so-called insidious water pollution, that is, effects of waste discharge upon the biota not readily apparent, is not unlike the problem the professional public health worker - doctor, sanitary engineer, and microbiologist - faced many years ago with respect to fecal or bacterial contamination of waters and water supplies from sewage discharge. At that time it was well known that intestinal diseases were water borne, that the biological agents were present in the waters but in unknown or unassayed concentrations, and that their presence was the result of uncontrolled sewage discharge.

It is of interest and in the writer's opinion worthy of the time to review briefly how, in most

cases, the problem has been resolved. And if it has not been resolved it has been solely because of lack of funds for necessary construction - not in any case because of a lack of technical knowledge about what should or could be done.

Briefly, the problem was approached, essentially simultaneously, on the following fronts:

1. Corrective measures (some type of conventional sewage treatment) for the obviously bad, or grossly affected situations.
2. Development and evaluation of methods for assessing the bacterial condition of the waters.
3. Quantitative assaying of existing conditions (essentially bacteriological) of the waters.
4. Surveys and investigations of the relation between the concentration of "indicator organisms" (coliforms - several species) with the presence of sewage discharge and the incidence of disease.
5. Epidemiological investigations of all factors affecting transmission of enteric disease with emphasis on the water as the carrier or vehicle.

A few points of emphasis should be indicated. Corrective action in obvious cases did not await precise resolution of all technical or scientific facts bearing on the problem. Similarly, in situ quantitative assaying with the best (at the time) indices of contamination was conducted to determine existing conditions. Intensive studies were conducted to select practical "indicator-type" indices of contamination, refine methods of analysis, and develop levels of significance and control for denoting the concentration of

indicator organisms present in the environment. Consequently, if the concentration of indicator organisms exceeded certain levels, although the levels may have been established somewhat arbitrarily, additional investigation of the significant factors related to the bacterial level was needed. Moreover, the data at hand generally justified the additional intensive study, the studies were almost invariably conducted, and ultimately the problem resolved.

How then does this relate to biological effects of water pollution? Directly, inasmuch as the foregoing example is one of the biological effects of water pollution, although not the one of major concern in this Seminar. Since the problem involved the concentration of organisms naturally occurring, as well as man-produced in the environment and their effect on or relation to man's health, the problem was just as difficult as the one of principal concern here - that is, the effect of wastes on aquatic organisms.

SPECIFIC NEEDS

What then does the engineer expect and need from the biologist to design works to eliminate or minimize the effect of waste discharge upon the environment? Very simply it is a quantitative biological description of the waters and sediments as they exist now and estimates of the effect of various concentrations of waste upon the significant and sensitive organisms present. The meaning of the key term quantitative in this instance is not precise concentrations of all organisms that inhabit the water and sediment; instead, it is intended to mean statistically valid data (which in some cases may be only orders of magnitude because of the variability of the characteristic measured) on the important organisms in the food chain of the economic (commercial, sport, recreational, etc.) fisheries. Also, the organisms deemed to be important now by the biological experts may, upon intensive study, be found to be not so important. Obviously, any list of such organisms must be subject to constant scrutiny and revision.

If water pollution abatement is going to be put on a rational basis, it will be necessary ultimately to develop quantitative estimates relative to the following:

1. What organisms of significance and in what relative concentrations are in the area at present.

2. What organisms of significance and in what relative concentration might be expected in the area under present state of man's development if the area was unaffected by waste discharge.

3. What is the time-concentration function of effect of waste upon the organisms of significance.

4. An estimate (crude at best) of the economic significance of the effect.

The preceding list of "required data" appears imposing and difficult to resolve or develop - and it is. However, in the writer's opinion, the problems are not so difficult that they are either economically impractical or technically impossible to resolve - at least within the limits of reasonable engineering and biological precision. Moreover, basic data collection on quantitative descriptions of existing conditions in areas presumed to be unaffected by waste discharge as well as in areas that are known to be affected can and will be justified on a water pollution control basis. In all cases quantitative data are needed to remove water pollution technology from the area of emotion as related to the individual's particular interest or concern in the subject.

The question exists, how should the biota be quantitatively described, in a systematic manner, at least on a trial basis. Obviously, this is a question that can be resolved only by expert biologists - but it must be resolved. The practical, quantitative description of the biota must be sufficiently complete to yield interpretable data to indicate minor yet statistically significant effects and to point out the need for more rigorous and extensive study of specialized problems. Also, the methodology must be reasonable and practical, not a "research of the universe" for each situation. In essence, what is needed is a mutually acceptable (biologist-chemist and engineer) quantitative methodology for biological assaying of the waters on a monitoring basis to attempt to ascertain minor, yet significant, adverse effects.

It is recognized by most workers in the field of water pollution analysis that physical and chemical characterization of the waters or the sediments is not adequate to describe pollutional effects on the biota. One of the most significant reasons for this is the inadequate knowledge of

the relation between the physical and chemical characteristics of the environment and the condition of the organisms found therein. Therefore, it appears to be an absolute necessity that if interpretable data are to be obtained it is necessary not only to quantitate the physical and chemical characteristics of the environment but simultaneously to quantitate the significant biological parameters. It is the writer's firm belief that it would be as unrealistic to conduct only biological investigations of an area as it is to conduct surveys consisting of only physical and chemical analyses.

What is most urgently needed from the biological fraternity is agreement, by the majority at least, as to what in situ determinations would best represent the general condition or health of biota. As previously indicated, it is not necessary to describe it in every detail, just sufficiently so that the results of quantitative assaying would indicate the need, if and when it occurs, and provide the economic justification for more intensive study. It is obvious that no single set of specifications would fit in detail each circumstance; however, there should be a minimum core of biological measurements that would suit every situation just as there is with respect to physical and chemical assaying.

ENGINEERING ANALYSIS

From an engineering point of view there are a few aspects of biological assaying that appear to be fundamental in character. First, whatever methodology is employed in sampling the environment, it must be quantitative in character and amenable to statistical methods of analysis. It is not sufficient to "flail the environment" to obtain samples of water and sediments and then run them through a routine analytical program. In fact the method and pattern of sampling the environment to provide interpretative samples and results is probably as important as the analyses performed. Sampling locations must be established to represent hydraulically the area of concern. The samples must represent accurately the character of the vertical water column where obtained and consideration must be given to effects of salinity or density gradients, extent of mixing, water currents or circulation systems, etc., as well as biological factors. The time and frequency of sampling must be selected with due consideration of the forces affecting the physical, chemi-

cal, and biological characteristics of the water column at a given point. Important factors include the magnitude of fresh water flow, tidal effects if present, temperature effects, time of day, season of year and physical factors other than waste discharge that also may produce significant effects. Without proper design of the sampling program with respect to variations with both space and time, the value of precise physical, chemical and biological analyses may be almost completely negated.

The sampling and analytical methodology must have a minimum of bias with respect to both analyses and interpretation. Also it must be sufficiently complete so that the results will permit statistically significant conclusions or interpretations - even if the only conclusion that can be reached is that more observations are needed before a statistically valid conclusion can be made. Until such time that quantitative data, susceptible to statistical analyses, are available on the condition of the biological environment, no real progress can be expected in the abatement of indirect and marginal effects or the so-called insidious pollution.

THE BIOLOGICAL DILEMMA

It has been the writer's experience to date that because of the dire lack of quantitative data on the biological characteristics of waters and sediments affected by waste discharge, those presumed to be unaffected, or in between, it is possible to obtain professional Ph. D. level biological counsel describing a given body of water and/or sediments in whatever manner suits one's preference by selection of the appropriate expert. The fundamental reason for this dilemma appears to be the almost complete lack of agreement (and absence of data) on how the biological condition of the environment can be assayed on an "indicator or monitoring type" basis. It must be recognized that to date monies have rarely become available, nor will they likely become available, for measurement of every organism or factor affecting the biota in a given potential problem area.

As soon as the biological fraternity develops or agrees upon a minimum, yet sufficiently extensive, realistic and interpretative biological evaluation program methodology, an enlightened sanitary engineering profession could and would include and could justify comprehensive

physical, and biological investigations or monitoring as fundamental parts of every significant waste treatment and disposal system.

However, as long as the biological expert or fraternity continues to occupy any of the following positions which so frequently have been occupied in the past, namely, (1) no need for any quantitative data as the problem is too difficult to quantitate. (2) If studies are to be made, they must include practically continuous observations of every organism in the universe or immediate environment. (3) All that is needed is an "expert" to make a detailed personal survey, and (4) the biological "expert-specialist" needs data only in his specialty, i.e., the ichthyologist wants data only on fish and thus interprets the overall condition, or cause and effect; similarly, the diatom expert selects diatoms as the organism of significance, the benthic expert polychaetes, etc., chaos and confusion will continue to reign relative to effects of waste discharge on the biota.

RECOMMENDED PROGRAM

The foregoing comments have been general relative to the need for and specifications of a comprehensive water pollution biological evaluation program. A characteristic of engineering generally is the need for action and decisions occasionally with limited data on which to base same. And the writer recognizes the hazard and risk related to decisions affecting specialty areas outside one's area of competence. However, occasionally because of the urgency or need for action, this must be done. It is with this background that the writer finds it advisable to suggest what might constitute a realistic yet fairly comprehensive water pollution evaluation program concerned with assessing the level of

the significant physical, chemical and biological characteristics of waters and sediments.

The ideal objective of such an investigation appears to the writer to include the following:

- a) Quantitation of the significant organisms in the water from microplankton to and including fish.
- b) Quantitation of the significant organisms in the sediments.
- c) Data on the diversity of organisms present in both the water and sediments.
- d) Estimates of the biological productivity of the area.
- e) Information on the condition of the organisms present.
- f) Quantitation simultaneously of the significant physical and chemical characteristics of the water and sediment.
- g) Correlation of the physical, chemical and biological characteristics of each.

Obviously the foregoing presents a giant undertaking. Some will say it cannot be done. Yet only factual data of the type described will prove the worth of the undertaking. In any event, it would appear to the writer that the first step in an orderly investigation would be to quantitate the levels of the principal organisms and physical and chemical characteristics as indicated in items a, b, c, and f.

With the preceding objective in my mind, a "core" water pollution investigative program outline as to recommended analyses is presented in Table 1.

Table 1. Recommended Outline of "Core" Receiving Water and Sediment Evaluation Program

WATER

Physical

- a. Temperature
- b. Transparency
- c. Total Suspended Solids
- d. Organic Suspended Solids
- e. Odor
- f. Visual inspection - floating debris, slicks, etc.

Table 1. (continued)

Chemical

- a. pH
- b. Salinity
- c. Alkalinity
- d. Biochemical Oxygen Demand
- e. Chemical Oxygen Demand
- f. Dissolved Oxygen
- g. Sulfides (if D. O. <1.0 ppm)
- h. Total Nitrogen and Nitrates
- i. Total and dissolved phosphorus
- j. Dissolved silica

Biological

- a. Coliform
- b. Phytoplankton (total - org/1)

Identification and enumeration of genus or species if possible representing $\geq 10\%$ of total population.

Diversity Index*

- c. Zooplankton (Total org/m³)

Identification and enumeration of genus and species if possible representing $\geq 10\%$ of total population

Diversity Index*

- d. Fish

Gill net, trawl, seine, etc. Number and weight of fish per unit of effort. Identification and enumeration of species $\geq 10\%$ of total population.

Diversity Index*

SEDIMENT**Physical**

- a. Temperature
- b. General lithological description

Chemical

- a. Organic carbon
 - b. Organic nitrogen
 - c. CaCO₃
 - d. Total sulfides
- Core samples

Biological

- a. Biomass (Total weight and volume of live organisms/volume or area of sediment). Orange peel or dredge samples

Table 1. (continued)

Biological

- b. Identification and enumeration of genus and species of organisms representing $\geq 10\%$ of total population
Diversity Index*

Surveys exactly as specified in Table 1 are currently in progress under the writer's general direction. While it is premature to comment until more data are available to permit statistical interpretation, nevertheless, the methodology gives promise of yielding significant interpretable data on the general condition of the water and sediments.

ation program will result in the development and acceptance of some "core" biological evaluation program that can be employed, with necessary modifications to suit local conditions, wastes, etc., to develop data that will permit a more quantitative estimate or evaluation of the effects of waste discharge upon the biota than has been developed to date.

CONCLUSION

It is hoped that the suggested pollution evalu-

*Diversity Index as used by the writer is the number of species, each representing at least 10 percent of the total population, i. e., 1-10. For a population where no species represents as many as 10% of the population, i. e., extremely diverse, the Diversity Index is the number of species representing 90% of the total.

The Diversity Index could be based on 5% of population but would require more extensive biological analysis.

THE USE OF BIOASSAYS BY THE WATER POLLUTION CONTROL AGENCY

G. E. Burdick - Senior Aquatic Biologist, N. Y. S. Conservation Department
Albany, New York

ABSTRACT

The advantages and disadvantages of some methods of bioassay and calculation of results are discussed in relation to their adaptability for the solution of specific problems of the water pollution control agency. It is concluded that the single solution and the constant flow procedures, in conjunction with the presentation of results as a TL_m or the logarithmic mean are adequate to satisfy most of the requirements of the agency. Short term field assay is discussed as a screening procedure to assure the presence of the toxic material for samples for laboratory bioassay and

chemical analysis. Use of synthetic waters and composite samples are considered unsatisfactory.

In addition, the field of effort that should be encompassed by the agency has been delimited. It is suggested that the activity in this field be restricted to the problems which cannot properly be considered the responsibilities of others, but are directly concerned with the effective operation of the law under which the agency derives its authority.

A number of procedures for bioassay have been published and the results have been presented by several different methods. The advantages and disadvantages of these procedures and methods and their suitability to the needs and responsibilities of the pollution control agency will be discussed in this paper.

The agency is primarily concerned with the behavior of specific wastes in specific bodies of water and their effect upon the use of the water for various purposes. The discharge of any waste may be assumed to set up a bioassay in situ which could be studied on location. However, the number of uncontrolled variables may make interpretation difficult and, in complex situations, impossible. The problems of the effect of other existing effluents must be solved, and it is frequently necessary to predict the probable effect of some waste of theoretical composition upon a certain water. In many complex industrial wastes synergism and antagonism may increase or decrease the toxicity of the constituents in which case even the most thorough knowledge of the reaction of pure compounds would be insufficient. Chemical analysis is often either impossible or too time consuming for use on a waste of changing composition. Laboratory or field bioassay may be

the only method by which the effect may be evaluated and functions to remove the answer from the realm of pure conjecture.

Bioassay involves a biological test of some substance under closely controlled conditions. The criterion for end point may be death or any other distinguishable physiological effect on the test organism that is stated or implied by the law under which the agency operates. Any living organism may be used in such a test, but the following discussion is intended to apply to the use of fish. There is no need to justify the use of fish to those associated with an enforcement agency, as they are well aware of the mass of complaints received when dead fish are observed in a water course. Industry is concerned with the bad publicity attendant upon fish kills and any practical method which can be used to prevent such occurrences.

Prevention of fish mortality is a duty of most control agencies and, where punitive measures are incorporated in the law, procedures must be developed and used to assist in determining responsibility. No single procedure, or method of evaluation seems adequate to serve all the purposes of the agency. Choice must thus depend upon the type of information wanted and the use for which it is intended.

The ideal bioassay is one in which the organism is subjected to a waste of theoretically uniform concentration in a solution of infinite volume compared to the size of the organism. The effects of temperature, constituency of the water and variations in oxygen, carbon dioxide, pH and other factors may then be evaluated. In practice, such an ideal situation is not possible, yet it must be approached to the extent that failure in approximation does not produce significant error. As long as the results are maintained within the limits of usable accuracy, modification of the ideal conditions is justified.

Field bioassay is a rough procedure usually involving only a few hours exposure to a somewhat concentrated dilution of a waste. It is used to assure that a collected sample contains the toxic substances in relatively high concentration. It serves to screen samples for chemical analysis, permitting weaker samples to be discarded without the need for the use of laboratory time for their analysis.

Laboratory assays may involve three procedures:

1. Routine, single solution exposure.
2. Routine exposure, with periodic replacement of solution.
3. Constant flow, or continually replenished solution.

All require maintenance of essentially uniform conditions if the results are to be interpreted, even though such uniformity is seldom found in the stream environment. The requirements of time and effort increase in the order of listing as does, usually, the accuracy.

1. Routine, single solution exposure.

The unmodified procedure must be for any evaluation of the effect of single applications such as would be used for the control of weeds and algae, undesirable fish or insects. It is also indicated for the determination of the presence of toxicity and as an industrial check procedure for the estimation of gross changes in toxicity accompanying variation in the effluent. Confidence may be placed in the result when it is known that the test fish are normal and represent the average of the population, that easily

volatile or readily decomposable toxicants are absent, or that reduction in toxicity due to the activity of the test organism does not occur during exposure.

Even a small loss or removal of the toxicant, or an oxygen concentration higher than the minimum legal standard will result in underestimation of toxicity. In computation of safe dilution from data derived by this procedure it is necessary to use a relatively high factor of safety. This may add considerably to the cost of treatment.

This general tendency to underestimation may be partially corrected, or even reversed, by an abnormal distribution of resistance, or maintenance of temperatures higher than those encountered in the stream situation. A possible fluctuation in the result is not too important in the establishment of a violation involving fish mortality. The procedure is used routinely in one of our laboratories to determine the presence of toxic substances and the dilution required to reduce their effect. There can be little question of violation when significant mortality occurs in dilutions equal or greater than those afforded by stream flow.

2. Replacement of solution at intervals.

This procedure can be used to periodically correct for reduced toxicity due to volatility, decomposition, or removal of the toxic agent by the fish. In the presence of oxygen demanding substances, the oxygen content will also be restored. It will result in the indication of somewhat higher toxicity with this type of material than the previous procedure, but it must be recognized that the exposure is on the average, less than the calculated initial concentration. The average concentration cannot be calculated unless the toxic agent can be determined chemically (see Figure 1). Increased handling of the fish may produce error. Where facilities for constant flow are available, its use cannot be justified.

3. Constant flow.

By this procedure change in the oxygen content or the concentration of the toxicant can be minimized by replacement at a rate commensurate with the desired accuracy. It requires

passage through the test chamber of either a mixture of the uniform flow of a concentrated solution with a measured volume of water, or a previously prepared and standardized solution.

The latter procedure is the simplest, cheapest and requires the use of less apparatus. Usually the rate of flow is adjusted so that an increased flow, or reduction in the number of test organisms, will produce no significant difference in apparent toxicity. As a reduction in flow may invalidate the results, the concentration in the solution should be checked after any extended period when the test has not been under observation. The test solution should be standardized in respect to oxygen and temperature and fresh solutions should be analyzed before use if possible. This is particularly important at low concentrations.

The method is best adapted for use with pure compounds and wastes of essentially uniform composition. It is the only procedure that can be used in an assay at a specified, uniform oxygen content. It is used in our laboratory to determine toxicity at the minimum oxygen content specified in the standards required under our law.

The water pollution control agency should be equipped to conduct bioassay, not only by the single solution routine procedure, but by some method of constant flow as well. The two procedures provide adequate tools to meet any type of problem that may arise.

Results from any method may be reported as TL_m for a specified time period, or the logarithmic mean time for death at a concentration

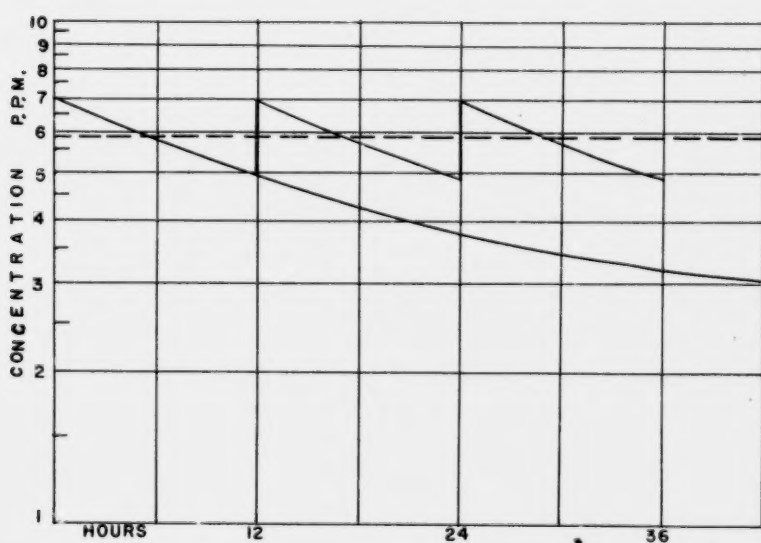


Figure 1. Concentration drop with time, and effect of replacement of solution. Average concentration with replacement (broken line).

and a curve of these times. The choice will depend upon the purpose of their derivation, the time that can be allotted to the determination and the accuracy required.

TL_m is the least laborious method of deriving a result since it requires only observation at a specified time followed by a simple method of graphical interpolation. However, it is less accurate and the results must be considered approximate. Preliminary exploration may be required for determination of the necessary dilution and frequently difficulty is experienced in properly bracketing the selected time interval.

In the results of individual experiments used for derivation of TL_m error is involved in the bisection of the interval between deaths by the specified time of observation. It must be assumed that the resistance of each individual fish in a set of 10 falls within and represents respectively the resistance of a 10 percent interval of the population. The inclusion of a single aberrant fish will produce an error of 10 percent in the mortality. Error is theoretically increased as the concentration is decreased to produce a longer time interval between deaths and more noticeable individual variation. The general mathematical principle that the mean and median tend to approximate each other would not apply unless the mortality was 50 percent or very closely approximates it. Even in that case inclusion of a weak fish which could be expected to be removed from a normal population within a reasonable period of time will produce error.

It can be calculated that it would require 10 times the number of replicates to obtain the same confidence limits that would be reached through the use of the logarithmic mean of the death time of all fish exposed to the solution. Aberrant behavior, or the inclusion of an abnormally weak fish, is more readily noted where the fish are under continuous or very frequent observation. The necessity for nearly continuous observation is the main disadvantage of the latter method. Too often adequate man power is unavailable even when the greater accuracy would be desirable. In any case, a decision must be made on whether the use of the result justifies the more time-consuming method.

In enforcement work to establish the responsibility for fish mortality by the control agency, there is usually no necessity for higher accuracy

than given by the TLm procedure. The need for a highly accurate result on an extremely variable industrial waste is questionable. TLm can be assumed adequate on this type of waste. Continued replication will increase the accuracy and it should thus serve the purposes of industry for industrial control work.

The use of the logarithmic mean is indicated for the study of pure compounds, or wastes of nearly uniform composition. The higher accuracy will permit a smaller factor of safety and result in lower cost of any required treatment.

Bioassay in the determination of the toxicity of substances to fish is not new. Reports of such assays date back many years. Standardized procedures have been available for more than 10 years. The use of the results by industry, the sanitary engineering profession and the pollution control agency is increasing. This can be expected to cause the demand for these determinations to pyramid.

A number of recommendations and formulae for "standard" synthetic waters have appeared in the literature. The reasons given for their use are similar to those for a synthetic standard B.O.D. dilution water. Industry and the control agency are interested primarily in the behavior of a waste in the natural water in which it is discharged. Reproducible results cannot be expected unless the same or an identical water is used to dilute a chemically identical waste sample. Results from a synthetic water would be of little value unless difference in chemical composition had no effect, or a correction factor could be applied to adjust for that difference. It is evident from the reasons given for the use of a synthetic water that there may be an effect from the composition of the water. Knowledge has not yet advanced to the point that a corrective factor can be justifiably applied.

The use of a composite sample is standard procedure in some fields of sanitary engineering. Its use is justified in chemical analysis of a variable waste where it is the intent to identify

all components, including some which may be intermittently present. The aquatic biota below the point of discharge are subject to all variations in the effluent and not to any average produced by a mixture of the wastes. The use of a composite sample for bioassay is therefore biologically unsound. It would be valid only if the waste was of uniform composition, in which case it would also be unnecessary. All assays conducted by the control agency and those accepted by them in support for clearance of plant or permits should be based on "grab" samples. These samples should have sufficient range in time and number to be considered representative.

Irrespective of the method in use, bioassay is time and space consuming. Availability of man power and the size of the facilities set a definite limit on the amount of this work that can be conducted. Assays should supplement chemical determinations only where the latter will not give adequate information with reasonable effort.

The control agency cannot afford to extend itself into phases of bioassay that may properly be required of the industry, the municipality, or the consulting engineer. The routine analysis of industrial wastes and the control of their quality is important, but is the responsibility of industry. The agency should advise on such problems and encourage the establishment and utilization of equipment for assay where it seems necessary to maintain the required water quality. Frequently the agency will be required to re-evaluate the literature on the toxicity of compounds in relation to the exposure of native fishes in the waters found in the state. Some of this may be undertaken in anticipation of future need. However, the bulk of their bioassays will be used to evaluate conformance to the standards set by their law, or the requirements of the permits they issue. It must not be forgotten that the primary responsibility of any water pollution control agency is to assure the proper functioning of the law under which it operates.

WHAT DOES INDUSTRY EXPECT OF THE BIOLOGIST AND HOW CAN HIS FINDINGS BE APPLIED TO INDUSTRIAL WASTE PROBLEMS?

Harry W. Gehm, Technical Advisor - National Council for Stream Improvement, Inc.

ABSTRACT

This paper deals with the application of biology to the manufacture of pulp and paper products and problems related to such manufacture, including effluent treatment and stream pollution control. The need for knowledge of the biological sciences has developed mainly during the last 15 years in this industry, and a wide variety of specialists are employed. The research on treatment of mill effluents involving biological processes and the application of such

processes to specific problems is gaining rapid acceptance. The use of biological surveys in conjunction with stream monitoring programs is gaining wide acceptance within the industry. Many other problems of a biological nature are apparent and are being given adequate attention. Some training in the biological sciences is recommended for all candidates for degrees in chemistry and chemical engineering.

Among the many scientific tools that industry employs today, biology is by no means the least of them. Since the writer is best acquainted with the application of this science in the pulp and paper industry, the scope of this paper will be confined to this subject. Practically unheard of in this industry thirty years ago, the biologist and related scientists are now expected by management to achieve many things, all looking toward a more profitable and comfortably operating enterprise. These activities are not confined to any one portion of operations but carry through from the procurement of raw materials to customer relations.

This broad scope is obvious from the following list of demands which the manufacturer makes upon biologically trained personnel:

1. Increase the yield of pulp per acre of woodlands.
2. Prevent the destruction of trees by disease and insects.
3. Prevent the destruction of cut wood and chips by insects and microorganisms.
4. Aid in the development of a suitable process water supply.
5. Prevent decomposition or molding of wet pulps.
6. Control slime growths in stock and paper machine systems.
7. Control the bacterial content of food packaging papers and boards.
8. Prevent undesirable odors of microbial origin in products.
9. Render products mold- and fungi-proof.
10. Render containers insect-proof.
11. Develop fermentation by-products from pulping wastes.
12. Devise waste treatment processes.
13. Keep a check on the aquatic environment in waters receiving mill effluents and establish criteria for effluent control.
14. Control nuisance growths in streams.
15. Mosquito control.
16. Conduct atmospheric pollution investigations where molds are involved.
17. Advise in the use of mill effluents for crop irrigation.

These activities and others as well, involve all manner of biological specialists from the geneticist to the microbiologist. Now so greatly in demand, it is amazing that only a few years back biologists were almost unknown in the pulp and paper industry. In fact, the really rapid growth of such activity has been during the past fifteen years.

The first two problems of biological origin which became apparent to the pulp and paper industry, were slime growth in paper stock systems and the fact that the discharge of spent process waters could have an adverse effect on aquatic life. The fact that slimes were of biological origin was not always understood. Many ascribed them to the accumulation of pulp fines forming masses of a hydrogel whose peculiar properties were due to its physical state rather than to microbial growth. Once the true nature of slimes was established, chemical methods for their control rapidly appeared. Many of these were applied haphazardly at first, with highly variable and frequently not too satisfactory results. It remained for the trained microbiologist to establish slime control on a firm scientific basis. Today, in-mill housekeeping and sanitation, bacteriacidal application based on analysis of the problem, improved wash-up methods, as well as better construction materials and methods of furnish handling, are all a part of effective slime control. Microbiologists employed by mills themselves, industry service groups, and slime control chemical manufacturers, have all contributed to this advance. Since slime control contributes substantially toward profitable paper manufacture, management is completely sold on the usefulness of the biologist in the solution of such problems. The same is true in respect to other factors of biological origin which contribute to manufacture of saleable paper products.

From here we move to the fields of biology, which found slower acceptance by industrial management since they do not contribute directly to profitable operation and frequently require investments which bring no financial return as well as representing a continuing manufacturing cost item. These are effluent treatment and stream sanitation. Peculiarly enough, acceptance of the importance of biology in these fields has also been relatively slow by industrial technicians. Most of these people were engineers and chemists who had no biological training, hence had difficulty in understanding biological

phenomena. It was hard for them to believe that bacteria were responsible for waste stabilization and the self-purification of streams, as well as the liquifaction occurring in fiber deposits. Untoward effects that mill effluents can have on the aquatic environment other than producing mass mortality of fish, gained slow acceptance by both management and technical personnel. Hence, at the start, advancement in this area was largely a matter of industry education. This has been accomplished in the pulp and paper industry through both private and public agencies. Industry-sponsored organizations such as the Institute of Paper Chemistry and the National Council for Stream Improvement, as well as universities employed for research on problems of this nature, have contributed substantially. The employment of biologists by agencies charged with stream pollution control, as well as by industry itself, has also been an important factor. The appearance of mill technicians with some background in biology, has also helped. In regard to the latter, it seems that some knowledge of biology is so essential in our industry and others today, that a course or courses in the fundamentals of biology and microbiology should be a requirement in the curricula leading to degrees in chemistry and chemical engineering. Even if the knowledge gained was never used directly, many of these people will in the future face management problems involving this science and through their training be better qualified to either present the facts to management or to understand the problem presented by the investigators, and hence be able to make correct decisions.

The fact that a good job of education has been done in the pulp and paper industry, is evident from the number and scope of biological research projects and investigations which have been carried on for some time and are increasing in scope and number. The almost universal employment of the biological stream survey as part of the establishment of new units of the industry and for monitoring purposes at established units, is additional evidence of management interest. University projects at the Institute of Paper Chemistry, Oregon State College, the University of Georgia, North Carolina State University and Louisiana State University, as well as four large-scale company projects, have contributed substantially to our knowledge of the effects of pulping effluents on the aquatic environment and oyster culture,

together with basic information on the oxygen requirements of fish. Cooperative projects such as that carried on by the Wisconsin Sulfite Pulp Manufacturers' League and the Wisconsin Committee on Water Pollution have been productive of basic information. Research on nuisance growths in streams is being earnestly pursued at Rutgers University and the Columbia River, a combined industry-government project. Research on biological treatment has been sponsored at Oregon State College, Purdue University, Louisiana State University, Virginia Polytechnic Institute, and Rutgers University by the National Council for Stream Improvement and development work in this field has been conducted by a host of individual companies, both on an individual and cooperative basis.

Over the last five years, the pulp and paper industry has conducted thirty-four pilot and demonstration plant operations employing various forms of biological waste treatment. Fifteen mills employ oxidation basins for stabilizing effluents, seven activated sludge, three aerated stabilization basins, and three trickling filters combined with oxidation basins. Eighteen projects involving the use of effluents for irrigation or their disposal on the land, are in operation. The following slides illustrate some of the activities mentioned above.

This is an impressive list as far as research is concerned; however, study is not an end in itself. Where has this research led us in terms of accomplishment in stream sanitation and have the results obtained met management acceptance? The efforts on biological treatment of mill effluents can be viewed as successful in

that such treatment is being increasingly applied in a number of forms by the industry. The fact that research and development led to much greater process efficiencies than previously possible, thus reducing capital and operating costs, has accounted for its present status. Management cannot be expected to be enthusiastic over cost items of this kind. On the other hand, such developments are acceptable to many of them since they can represent solutions to annoying problems, allow increased production, or new production at locations where it would otherwise not be possible if adequate effluent treatment techniques were not available.

Knowledge of the aquatic environment and the effect of mill effluents upon it, has been very useful in defining waste treatment requirements, preventing fish kills and protecting mills from false accusation regarding the effect of their discharge on fish life and abundance. The reaction of management to such work is generally a function of the attitude of agency biologists interested in fish and game management and stream sanitation. When a real problem exists and a cooperative objective approach is suggested, it is surprising the degree of interest and support that management will lend to such study.

It can be concluded that biology is playing an important part in the development of methods for the definition and abatement of industrial pollution and will continue to do so to an ever increasing degree. Acceptance and approval by management is certain to follow sound accomplishment. No one can rationally argue with success.

APPLICATION OF BIOLOGICAL FINDINGS TO WATER POLLUTION PROBLEMS IN LOUISIANA

K. E. Biglane, Chief - Division of Water Pollution Control, Louisiana Wildlife and Fisheries Commission, Executive Secretary, Louisiana Stream Control Commission

ABSTRACT

This paper relates the views of water quality control and abatement procedures of a state authority, whose aquatic researches and policies are guided by a predominately biological

staff. Some discussion is given regarding yardsticks used in measuring the progress of Louisiana's pollution control program.

Because Louisiana's water pollution control agency has its investigative staff supported by the legislative body authorized to carry on wild life and fisheries conservation in the state, water control management policies and research are guided by a predominately biological staff. As a biologist, I have been led to believe that this situation is unique for it is also my duty, as Chief of this staff, to act as technical advisor to the Louisiana Stream Control Commission, the state authority for water quality control. Since this position seems to be occupied by Engineers, mostly Sanitary Engineers, in other states, I have been asked to express our agencies' views on water quality management and explain those techniques which we incorporate in pollution abatement procedures. Let me state from the beginning that both the engineering and biological fields, as they pertain to water quality management, are recognized by Louisiana to be entirely dependent upon one another and both fields are fully exploited so as to gain the maximum knowledge of our surface water quality problems.

As a Board Member appointed by the Secretary of Health, Education and Welfare to the first interstate pollution hearing under Public Law 845, as amended, I had an excellent opportunity to appreciate and utilize both the engineering and biological fields of endeavor as they pertain to water quality control. As a present Committee Member of the State and Interstate Water Pollution Control Administrators I have been in a very favorable position to receive and

reflect upon the national views of those professional men who administer to water supply, demand, and research.

It may be that our office is more critical than the Sanitary Engineer regarding what may or may not be harmful due to a man made change in a natural aquatic environment. For example, a state or federal public works project that has been initiated with little or no regard for aquatic habitats can and has moved the Stream Control Commission to act quickly and order those steps which would minimize the effects of slush disposal from channel dredgings or spoil deposits. Although these projects may be designed to keep large rivers from coursing out of their natural channel, or to aid in flood control, or to provide boat passage, the wastage from these operations can irrevocably change the game and fish habitat in many thousand acres of inland streams and bayous. Fine silt particles that remain in suspension can turn productive game and commercial fishing areas into little more than desertal voids. This aquatic smog accompanied by the heavier precipitable particles has been demonstrated by many observers to be irritating to the sensitive gill membranes of fishes or directly fatal. Spawning nests and the small invertebrate animals that serve as food for fish are smothered out by layers of soil particles constantly raining down upon their bedding places. Our fieldmen have observed many instances of this type of environmental alteration and have found its effects to be even more lasting than the majority of our industrial wastes.

We are often faced with the "why bother" line of resistance from those groups who loudly assail any comparison between keeping their lands or homes dry or sacrificing a "few fish". The "why bother" group also enrolls those citizens who are fatalistic in their belief that the inroads of man spell a near doom to our natural wildlife resources as we presently know them. Such an attitude, if it prevailed, would make this a certain truism. The practices of wholesale acreage clearing for residential subdivisions; the oil or gas pipeline and highway rights of ways; the dredging through and subsequent destruction of oyster bedding grounds by drilling barges and rigs moving to offshore sites; the girdling of thousand of acres of hardwood trees for soft pulpwood production; the mining of millions of cubic yards of sand and gravel from our clear, swift, recreational streams; the leveeing off of our inland bayous and feeder streams for reservoir capacity ultimately making them unfertile, stagnant environments, forevermore deprived of the benefits of natural water fluctuation, make it easy to envision how such thoughts are engendered. Certainly our game and fish communities will respond adversely to these types of inroads - progress, if you like, if sound management practices are not continued and enhanced. All of these things just mentioned affect the management of a watershed and our office must weigh the consequences just as much as the discharge from an oil refinery or a chemical plant. In many respects it is fortunate that we are directly connected with the state wildlife and fisheries authority. The advantage of receiving data from the Biologists in the Game and Fish Division has been invaluable for most assuredly our small Division staff could not spend enough hours in the field to assay these effects of man's operations. Ultimately, this data is injected into our decisions regarding municipal, agricultural, industrial and recreational water supply needs and quality.

The widespread application of organic insecticides appear to pose another serious threat to wildlife communities in the field and in the stream. State Conservationists recently became alarmed over the reported deaths of geese, quail and rabbits from Heptachlor - a poison used to fight fire ant infestations. Bioassay tests conducted in our laboratories have shown these materials to be highly toxic, in low concentrations, to fish and other aquatic animals. Last year our office became concerned over the streams in the vicinity of the sugarcane fields

when a number of fish kills occurred coincidental with the aerial application of Endrin - an insecticide used to control the sugarcane borer. We realize that these materials have been established as permanent agricultural pest control tools and consequently we have to take the position that they will be continuously used. What then is the best abatement action? As a first step the Stream Control Commission ordered our office to begin the drafting of regulations designed to bring to the attention of the airplane pilots the dangers to wildlife of the materials they were using. Also, the regulations were to cover flight patterns designed to prevent the release of these poisons directly over a waterbody or applying these materials in such a manner that prevailing winds would deposit them into a stream or pond. A meeting was held with the Louisiana Aerial Applicators Association and a number of important facts were learned. It was brought out that those poisons contained in a heavy, granular vehicle such as starch or clay were less apt to be wafted about the countryside by prevailing winds. Spot poisoning was possible using this material and the pilot did not have to get down to cotton boll or cane joint level to assure complete coverage as so often is the case when dusts are used.

The pilots were cautioned to pay more attention to weather predictions for poisons applied during the morning and washed away that evening by rain would just have to be reapplied the next day. Of course the farmer is going to point this out if it happens too many times because he is paying for each application.

The insecticide manufacturers in our section of the country were advised to do more researches which would indicate the optimum lethal dosage per acre and caution the landowner not to exceed this.

It is hoped that the close cooperation now enjoyed between the aerial applicators, the insecticide manufacturing industry, the agricultural and entomological research groups, and the Stream Control Commission will keep the adverse effects of these materials toward wildlife to a minimum.

What then, is the philosophy of water quality management from a state water pollution control authority technically advised by a predominately biological staff? Does it lean more heavily toward protecting forest and pond life rather than

the overall health and water needs of the general citizenry? We think not. The record shows that our methods of attack have virtually eliminated water contamination from almost 50 sugar mills in the state, each having a condenser water discharge of nearly 200,000 gal/hr containing entrained sugars. It was found that limiting the pounds of BOD/day discharged by each mill and basing it on the assimilative capacity of the receiving stream in its average annual flow during the grinding season, would significantly reduce the effects associated with organic loads. This particular situation could be improved markedly if more water could be introduced into watersheds in these coastal and near coastal areas that are affected by tidal actions. At extreme low flows these streams have little or no positive flow and would probably stagnate from natural organic loads supplied by runoff from the swamps and nearby cultivated fields. To alleviate this situation, this office has calculated the requirements and recommended additional flowages be introduced into the headwaters of these basins. This additional water could be obtained through lock controlled canals emanating from a larger river in the immediate vicinity. Here is a situation where our technology of control of an industry waste has advanced about as far as possible utilizing the existing technical data. Action now calls for more research on further organic load reduction by the sugar industry and/or more dilution waters provided by public moneys.

At one time the paper mills in the state were the largest contributors of untreated waste to our natural waterways. Civil damage suits amounting to over \$1,000,000, were leveled at these concerns before, during and after the war years. Active encouragement by the State Stream Control Commission and cooperation by industry has helped turn a once seemingly hopeless situation into a satisfactory arrangement both to the public and the mill managements. One mill purchased 5,000 acres of a nearby swamp and constructed a ring levee around it. This basin, representing over 1 billion cubic feet of available waste storage, receives the total effluent from this large kraft mill plus approximately 1,000,000 gal/day of primarily treated domestic sewage from a nearby town. BOD analysis of this huge oxidation pond reveals a 90% reduction of organic load demand. But, even more important, this area has been turned into one of the most productive water-fowl hunting locations in the South. The wealth of nutrients

supplied by the mill waste and the sewage causes annual, luxuriant growths of Lemna (duck weed), a prime duck food.

Research on abatement handling of oil well drilling muds has already been described in a previous paper (Biglane, 1958). It has been observed that these materials can play havoc with bottom dwelling forms, fish, and domestic animals. These muds are caustic (pH 9 to 12.5), contain refined or crude petroleum in concentrations ranging from 1 to 4 percent, and a variety of other materials designed to give the muds weight and circulation control. A recent investigation by our field personnel revealed the loss, by oil contamination, of approximately 45,000 sacks of oysters from drilling muds carelessly disposed from one rig. Since abatement procedures with this type waste are known, stringent enforcement of our anti-pollution laws are demanded and the offending company was punished \$37,000. This does not include the money the oyster fisherman will certainly collect for his loss.

Our agency actively encourages private research by industry to minimize or correct the damages caused by their wastes. The petroleum refining industry in Louisiana has been one of the leaders in these endeavors and through their Louisiana Petroleum Refiner's Waste Control Council they have accomplished a tremendous amount of effluent quality control. Elsewhere in these proceedings, Mr. R.A. Lafleur, Assistant Chief, will devote an entire paper to this subject.

At about this point we should attempt to develop our definition of pollution and speak of those yardsticks by which we attempt to measure the success of our program. Before charging directly into these two points let us first consider a few important facts. Since January 1956, two important developments have changed the scope of water quality control in Louisiana and perhaps the entire South. The first was the passage of Public Law 660, the Federal Water Pollution Control Act, 84th Congress. This legislation contained a section which provided municipalities with monetary allotments, on a matching basis, to aid in the construction of municipal sewage treatment plants. In the beginning, we recommended that this particular section be administered in Louisiana by our State Health Department. The recommendation was accepted and the project is being ably

handled by Mr. John Trygg, Director, Division of Sanitary Engineering. The success of these Federal Grants in stimulating the construction of sewage treatment facilities has been very gratifying and Mr. Trygg's office is to be commended for a job well done. This leaves our office free to concentrate all of our efforts on industrial wastes and other man made changes to our ecology.

Beginning early in 1956, the second major development was depicted by the resurgence of big industry migrating South and in many instances situating along our major watersheds. Chemical, petro-chemical, metal ore refiners, petroleum refiners, food processors, canners, and paper manufacturers have found Louisiana to be an ideal location for their activities. The development of natural resource minerals reached an all time high in the last decade. Petroleum fuels and by-products from over 24,000 oil or gas wells, in nearly 800 oil fields, comprised 9 percent of the total value of minerals produced in 1956 (Interior, 1956). Recently the State received \$54,000,000 in oil lease revenues for new developments along the coast. The State produced 40 percent of the nation's sulphur in 1956 and mined 4 million tons of marine shells and nearly 10 million tons of sand and gravel. We cite these figures to impact the complexities any water pollution control administrator must consider whether he is an Engineer or a Biologist because all of the above mentioned processes utilize water and have a waste stream. All of Louisiana's major cities and industrial complexes are located on a major watershed and it is so easy to use this waterway as a means to dispose of unwanted and unknown products and herein lies the crux of our considerations.

(1) We are a downstream state receiving the multi-used waters from nearly two thirds of the United States in our 5 major interstate river basins and in my opinion, this discounts the use of stream standards as such. We must rely on upstream state control, federal interstate water pollution laws, and interstate river compacts to give us water quality control from the very beginning.

(2) It is not always economically feasible or geographically possible to significantly in-

crease the second foot flowage in all watersheds by the introduction of water from nearby basins. Therefore, it is our opinion that water quality adversely downgraded by industrial effluents is conversely upgraded proportional to the technology of control exerted on the effluent. Many times, and perhaps rightly so, an industry wants effluent component figures to "shoot at", especially with organic wastes. We have been unable to arrive at such magical figures without considerable exploration. One industry in our State discharges nearly 10,000,000 gal/hr of effluent coming from nearly 100 separate petroleum refining processes. Once in the receiving river it flows nearly 13 miles, hugging one bank, before it receives the full dilution afforded by all of the river. In our field investigations we are finding out more and more harmful effects (and these are not necessarily limited to fish and other aquatics) from this and similar discharges. Taste and odor problems are becoming more and more in the main. Therefore, any yardstick for measuring the success of Louisiana's program would certainly have to include the amount of researches carried on by State and Federal agencies, and industry, to advance the technology of control over effluents and their unknown, but evident effects on water quality.

(3) There seems to be a constant demand by professional and lay groups for an all inclusive definition of (water) pollution. After years of hearing such phrases as "too much of something", "unreasonable impairment" or "organic enrichment", we have come to regard the word itself as undesirable. Each professional field associated with water quality management has its own ideas regarding a definitive expression of pollution and also those yardsticks by which it may be measured. A lay speaker conversing about an adulterated body of water can probably instill more disgust and horror in the general public's mind just by intoning the very word, than all of our technically descriptive phrases put together. For these reasons, we define (water) pollution as "a word that is generally used to infer that there is an objectionable characteristic (or characteristics) to water. The degree of the 'pollution' many times is reflected by the individuals interpreting".

REFERENCES

Biglane, K. E. 1958. Some Current Waste Treatment Practices in Louisiana Industry. The Thirteenth Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana.

The Mineral Industry of Louisiana in 1956. U. S. Department of the Interior, Bureau of Mines, Area Report IV-59, 1956.

BIOLOGICAL ASPECTS OF INDUSTRIAL WASTE PROBLEMS

Charles E. Renn, Professor of Sanitary Engineering
The Johns Hopkins University, Baltimore, Maryland

ABSTRACT

The present pattern of biological investigations associated with industrial waste disposal stresses (a) changes in the downstream ecology, (b) toxicity of wastes and the tolerance of fish and fish food organisms to diluted or treated wastes, and (c) biological changes of the waste and associated changes in water quality. These measurements are chosen because they utilize standard facilities and give answers to the most obvious questions.

There has been relatively little work on the physiological action of wastes upon aquatic invertebrates and vertebrates, or upon plant life. Exceptions exist, such as the investigations of the pharmacology of anticholinesterase insecticides, and the accumulation and distribution of fission products in

fish and marine plankters. The lack of activity in physiological studies appears to be related to the decline of physiology courses as a part of formal biological training in universities. Most of our appreciation of the interrelation of water quality and aquatic life rests on an earlier background. We prefer to anticipate the effects of wastes in physiological terms where possible; they tell us how the waste components act and furnish valuable leads to treatment techniques. A number of examples may be found in recent experience.

It is unlikely that laboratories associated with regulatory agencies will develop physiological information. This function is better served by specialized investigators associated with industry and with research organizations.

"Pure" scientists frequently point out that the large masses of biological observations and data that we've accumulated have yielded few generalities that can be described in quantitative terms. In the face of this superior criticism, I suppose that there are no good grounds for being upset with the view taken by many sanitary engineers, that aquatic biologists are insensitive to the elegance of numbers applied to "steam sanitation".

This lack of concern among the knowing is supposed to block the full flowering of the profession. I should point out that a metaphor based upon any characteristic of the spermatophytes is hazardous; some produce barely detectable flowers and go to seed early.

I think that we are dealing with somewhat different types of curiosities when we have biologists and engineers in the same room. Biologists and engineers have reasons for looking at problems in different ways. The engineering professions are based upon packaged bits of information that have been organized so that they may be used efficiently to make money. A great deal of thought and experience has been put into packaging these items of information to

make them completely dependable, even in the hands of people who don't understand them very well. The engineer has a job to do, and he must know if he can do it, what it will cost, and when it can be finished, and how long the operations can go on after they are set up. These requirements make a man somewhat conservative in his choices, and he naturally becomes less happy as he approaches the limits of reliability.

Everything in the training of engineers is directed to making a man who is reliable and responsible in the design and administration of other people's affairs. By the time that he has completed this training, he will know what elements he can control and what he can't, and depending upon his temperament, he will pick work where he can be sure things will be within bounds, or he will devise a system of insurance against the elements that he can't anticipate. In any case, the engineer tends to associate "knowing" with controlling, and to regard the unknown as out of control. This is to be avoided.

Only a small fraction of men who formally study biology treat their specialties in such an organized fashion. Some biologists have been great administrators and successful business

men, and a great many biologists work for salaries. But there is nothing in their professional equipment comparable to the pre-assembled, conveniently packaged, selected bits of information that an engineer uses.

This is to be expected. The many separate branches of biology have their sources in the amateur point of view, and especially in that of the true, inquisitive dilettante. The early biologists were men of great learning in many fields, and observation of and inquiries into the behavior of living things was a stimulating part of their general diet. Later, men of wealth and leisure made extensive travels, studies, observations, and collections. Together with the passionate amateurs they laid the systematic base of zoology and botany. The work was done for fun and for intellectual refreshment by people who were not concerned with money. The nearest that biology has come to producing a profession is represented by modern medical and agricultural research. These employ by far the greatest fraction of our salaried biologists.

The essential quality of good observers and research people, generally, and of biologists especially, is a concern with the details of function and structure. There is great satisfaction in discovering continuities and similarities, but there is even more excitement to be found in the parts that do not fit the accepted pattern -- in the very sections that engineers and managers regard as unreliable or uncontrollable. The biologist wants to know what is inside the black box. He may also take great pleasure in trivial and incidental ornamentation. Time is not important; costs and profit aren't, either.

The psychological position of the sanitary engineer who attempts to administer stream studies involving much biological work is unenviable. A certain obliviousness is necessary. As one of the more successful operators in the trade has put it, "We live by our wits".

It is obvious to anyone who is active in the field of water resources that any improvement in water quality through waste abatement and control will come through the interest and efforts of large water using industries, essentially through the concern of people who have lots of other things to do, and who must judge the relative importance of water resources and other values in their communities. We do not seem to have large reserves of competence. The

question that we should consider here is the place of the biologist in the evaluations and decisions that must be made.

To begin, we should recognize that biologists have played a relatively minor role in water resources planning, and in the development of water and waste treatment. The numbers of biologists who are interested in these fields, and who have a useful degree of experience, is limited. It is true that many of the concepts applied in the development of stream standards and in the justification of individual regulations used by various agencies were borrowed from observations and recommendations of workers of the U. S. Fish and Wildlife Service, and from the older Biological Survey. Various state biological surveys and interstate groups also contributed. But the number of biologists was never large, in no way comparable to that of the various sanitary engineering groups who were involved more persistently. The biologist played a secondary role in these initial steps, he was hitched to the operation to give it what is known as balance -- but certainly not to run it.

Second, we should note that the number of specialists employed by industry for waste abatement operations is very small. Only a few large companies have full time staffs. In practically every case these specialists are assigned to central services and must be capable of carrying out many types of water handling engineering operations -- and other works as well. Many of the more distinguished members of this small group are not sanitary engineers by training, but have developed outstanding facility as a product of their interest, ability and experience.

Third, the fraction of civil, chemical, and mechanical consulting engineering service directed to industrial waste treatment is comparatively small. A large part of this small requirement is furnished by a few of the larger manufacturers of water and waste treatment equipment. The original investigating and planning effort is minimum.

Fourth, the few biologists who specialize in industrial waste investigations as a private enterprise are not notably swamped with work orders ahead.

In the face of these conditions, what future has the biologist in the industrial waste phase

of water resources. Some of the answers are obvious. Most biologists, and probably the most able and aggressive, will not concern themselves with it at all. It will not attract them.

A few will fill the niches provided by various civil and federal programs. The impact that they will make, if impact is the word to use, will be something like a dropped powder puff, but the table of organization will be satisfied.

Finally, a few will enter industries or work with them. They will undoubtedly have to be versatile and alert if they are to have worthwhile professional futures. There is no moral to be pointed out here. Good engineers and chemists must be versatile, too. There's no reason to believe that a biologist need be less adaptable or less capable of growth than other professional men.

Industries recognize their need for advice and assistance from biologists. This has become more evident since World War II, as plant sites requirements have become more exacting. Biological surveys have been extremely valuable in assessing the natural resources of areas that may be affected by wastes, in estimating the allowable waste load, and in projecting the requirements for waste abatement. Resurveys are frequently made to check the effects of changed operations, and to determine the feasibility of plant expansion. Industries prefer that such surveys be made by outside institutions. The state of affairs described by a survey is a document. It becomes much more valuable, and gains other use when programs of resurvey studies are added, and the varying conditions of the stream under seasonal flows, and waste loadings can be established.

A second, relatively obvious use of biological techniques in waste programs is the biotesting program applied to toxic wastes and to wastes that cause tastes in edible fish. In general, this type of biological program is most effective when it can be carried out at the plant producing the waste, as part of the laboratory or pilot operation. This is evident. But it is not often that the space, facilities, and talent is available for work on the spot. Compromises must be made in setting up systems where the laboratory facilities are available.

The point that should be clear is that there are very few industries that can justify the full

time employment of a biologist specializing in waste problems, or of a group of biologists. Some industrial trade associations, most notably the paper pulp manufacturers do support continuing university programs of research on the more common waste problems, and maintain staff aquatic biologists to assist in special individual problems. Most industries prefer to arrange contract research programs with industrial research departments of universities or research institutions to explore specialized biological problems associated with industrial wastes. This makes good business sense. Universities and institutions can furnish or secure biological assistance of the type needed more conveniently than many industries can. The integration of unusual personnel is often difficult and expensive in industries.

The stream survey, the biotesting program, and the reporting of biological stream conditions have become accepted parts of the services offered by biologists concerned with water resources.

There is a very large field of aquatic biology which has been overlooked. It is worthwhile to point out that this includes the fraction that contains the recognized "principles", and that it was once used much more effectively than we are using it today. This is the part of biological science that relates animal and plant behavior to chemistry and physics and makes these understandable and predictable for engineers. We have been so concerned with checking out allowable waste loadings, documenting the state of the river, and certifying the rightness of affairs, that we've overlooked the way that living things work.

How does it happen that we are so little concerned with the physiology of aquatic organisms? I think that I know the answer, and it's not very complimentary. You can say, as I have, that physiological studies yield less sensitive indications of the effects of industrial wastes upon aquatic animals and plants than less expensive and less time consuming toxicity studies. If test fish live or die, this tells us something that is useful, but how do we interpret irregular humps in the brain waves of a sick carp?

Clearly, there are separate levels of interest here. The first says, "We need to know the state of things. We'll find out how much waste we can add without damaging the stream, and

we'll back off as much as we can afford from this level. In that way, we'll be good citizens and we'll keep out of trouble".

The second says, "That's dandy, we'll do just that because it is a sensible and direct answer to our immediate problem. But let's find out how the wastes act on living things so that we can understand as well as control. This will give us something beyond immediate experience that can be generally useful".

The arguments in favor of extending investigations into the physiological action of wastes are these:

First: If we can discover how a waste component or a group of wastes act on representative organisms, we can plan the abatement program rationally. As it is now, we direct our attention to materials that have histories of killing and water quality deterioration. But we are producing new materials in wastes the biological properties of which are not well defined.

Second: If we paid attention to physiological activity of waste bearing waters we would be able to develop a sound system for diagnosing the causes of fish mortalities and deterioration of bottom life. There are comparatively few types of wastes which produce distinctive symptoms in affected fish. And there is at present only a limited number of waste components which can be identified as damaging in blood and tissue.

Third: Describing the reactions of waste bearing waters and organisms in physiological terms brings together the varying factors that determine tolerance in an understandable way. We note that temperature, pH, dissolved oxygen, and many other conditions moderate the action of toxic wastes. The mutual action of these variables is much more understandable if they can be given in terms of the physiology of the organisms. All living things adjust themselves to wide variations in the natural environment. We need to know the range of these adjustments and the rates at which they can be made. While this may sound like a heavy order, it does give a better working picture to chemists and engi-

neers involved in waste abatement than a catalog of allowable limits does.

It may be worth recalling that a great deal of the more effective work on the action of industrial wastes on fish and other aquatic animals that was done by the Biological Survey and by the Fish and Wildlife Service was given a physiological backing. Dr. Ellis' investigations were given special cogency by physiological diversions into the mode of action of wastes components. At this time, prior to World War II, a number of leading physiologists made useful contributions to the understanding of the way in which fish adjust themselves to environmental changes.

In the interval, we have had a great reworking of the literature on the toxicity of waste materials. We have added little to the useful understanding of the physiological response of aquatic animals, though we now have available techniques and equipment that is beautifully adapted to this work. Enzyme chemistry, for example, has been exploited most effectively in the development of practical methods for distinguishing fish damage by some of the new insecticides. Radio-chemical techniques have been applied extensively to studies of the uptake and concentration of fission products -- but these methods and much of the original information may be used in the examination of mineral metabolism and heavy metal complexing in living systems. Histochemical techniques of great sensitivity and specificity have been developed.

With these modern advantages, biologists are in an excellent position to fill needed and critical gaps in the technology of waste abatement. In estimating the possibilities for realization, it may be helpful to consider that the first burst of progress in the physiology of aquatic animals -- of insects and fish -- was an incidental outgrowth of a strong interest in comparative physiology common to many university biology departments. In the interval this has been displaced by more current interests. The new physiological attack will have to be made directly, we can't anticipate progress from the accumulation of happy accidents. The question is this, "Who will do it?"

EFFECTS OF PULP AND PAPER MILL WASTES ON THE MARINE ENVIRONMENT

Michael Waldichuk, Fisheries Research Board of Canada,
Biological Station, Nanaimo, B. C.

ABSTRACT

The effect of pulp mill wastes on the marine environment depends on (1) volume and characteristics of the wastes and (2) volume and behaviour of the marine waters receiving the wastes.

Kraft (sulfate) pulp mills recover the salts and organic substances contained in their "black liquor" originating from digestion of wood chips. Sulfite pulp mills generally discharge their waste liquors untreated into an adjacent water course. Other pulp and paper operations, such as debarking, groundwood production and paper making, yield wastes which are chemically quite harmless but contain large amounts of suspended material.

Pulp mill wastes can be harmful to marine life in three ways: (1) direct toxicity, (2) indirect effect through oxygen reduction in the water, and (3) long-term effects on the bottom and water adjacent to it. Kraft mill wastes contain more toxic constituents than wastes from either sulfite or groundwood. Because sulfite waste liquor contains a high percentage of organic constituents, particularly wood sugars, it severely reduces the dissolved oxygen content of the receiving waters. Most pollution from pulp mills is caused by this effect. Long-term damage to the marine environment is caused by certain cumulative factors which render a gradual change in the aquatic balance of nature.

Three major types of marine systems receive wastes from pulp mills on the British Columbia coast: (1) Inlet, (2) Restricted Embayment, and (3) Tide-Swept Channel. Of nine pulp mills in production on the British Columbia coast, five have been built since World War II and four of these are Kraft producers.

INTRODUCTION

British Columbia is dependent on its forest resources for its primary industry. Pulp and paper mills convert a substantial proportion of the cut timber to the finished or semi-finished cellulose products. Because the sea coast offers many advantages in low-cost hydroelectric power, economical water transportation, and proximity to the lush forests of the seaward side of the mountains, all of the existing B. C. pulp mills are located on tidewater (Figure 1). Nine large pulp mills are in operation, four of which have recently undergone major expansions.

A sulfite pulp mill at Port Alice discharges its wastes into Neroutsos Inlet on the northeast end of Vancouver Island. Pollution is intensive at the surface within several miles of the mill sewer outfall. While bottom fish still dwell in the deep water and some salmon migrate through the inlet to and from tributary streams, the surface water is low in dissolved oxygen and supports virtually no life.

Wastes from the Port Alberni Kraft pulp mill enter Alberni Inlet and have been controlled in strict accordance with prediction calculations of dissolved oxygen supply in the inlet waters. This prediction is based on the amount of water discharging from the Somass River at the head of the inlet and the characteristics of the inlet water.

It has been found most efficacious in an inlet to discharge wastes at the surface, so that river water entering the inlet can flush the wastes out rapidly. In a restricted embayment, it has been found preferable to discharge wastes into deep water outside the bay, so that mixing and rapid dispersion can be achieved. Osborn Bay is an example of this type of system, where a Kraft pulp mill at Crofton discharges its wastes through a diffuser into the deep water of Stuart Channel. The effect of the wastes from this mill on oysters in the vicinity of the outfall is being studied.

A pulp mill at Duncan Bay, near Campbell River, on the northeastern side of Vancouver Island, discharges its wastes into tide-swept Discovery Passage. Tidal currents in this relatively narrow channel are swift and the water is turbulent. Very little pulp mill effluent can be detected outside the immediate vicinity of the pulp mill outfall.

Five of these mills are located on Vancouver Island, all having deep-sea approaches.

British Columbia pulp mills are located on one of three general types of marine features, - (1) inlet, (2) restricted embayment, and (3) tide-swept channel. All these marine areas have the general estuarine characteristics where fresh water added from precipitation and runoff exceeds that lost to evaporation. As a result, there is always a shallow brackish layer on the surface of a much deeper and denser sea water layer. This is a property of much importance in the behaviour of wastes added to these waters.

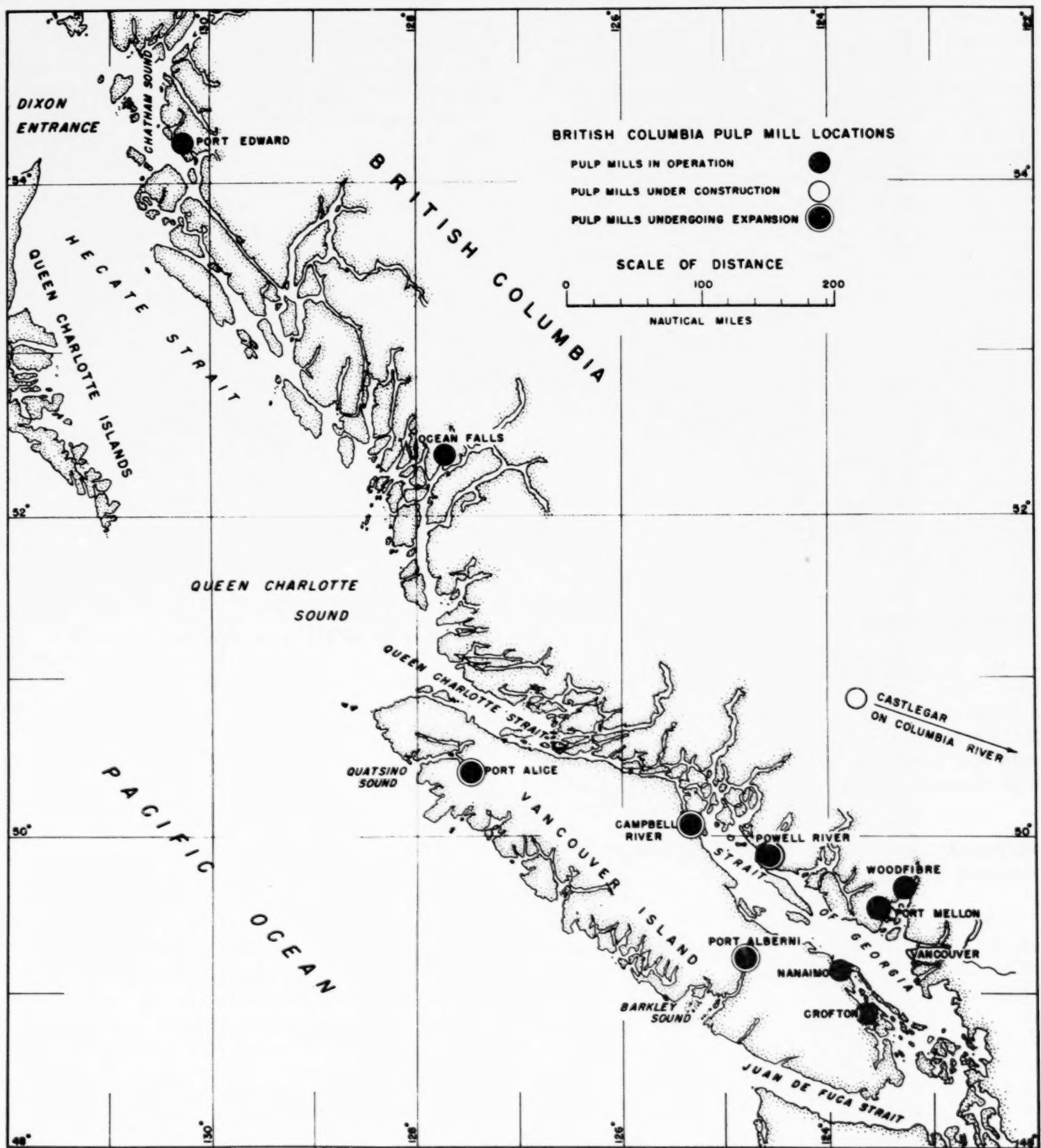


Figure 1. Chart of the British Columbia Coast showing the location of pulp mills.
 Note: Production at the Woodfibre pulp mill has been suspended indefinitely.
 All expansion programs shown were completed by the end of 1958.

Industrial pollution of marine waters is of considerable concern to the economy of British Columbia. About 10 percent of its resources come from the sea. Among these resources, the Pacific salmon fisheries are the most important. Five species of the Pacific salmon, genus *Oncorhynchus*, spawn and spend the early stages of their life history in fresh water. Then they migrate to sea by way of the many streams. Pollution can create a serious hazard to these downstream migrants and to the adults returning after anywhere from 1 to 5 years at sea, depending on the species. Because pulp mills are often located near the head of an inlet into which a fairly large-sized stream supporting runs of salmon and trout, may be flowing, the pollution barrier from the mill wastes may be located where it can be most devastating. In addition to these anadromous fishes, which are most vulnerable to industrial pollution, there is a hazard also to the various pelagic fishes, such as Pacific herring, smelt, and capelin. These come inshore to spawn and may enter the lethal zone created by pollution. Molluscan shellfish, particularly oysters in British Columbia, because of their sedentary nature and their shallow-water habitat, can be seriously affected by industrial pollution.

Mr. A. D. Mitchell of MacMillan and Bloedel, Ltd., Port Alberni, made the weekly determinations of DO and BOD on the waters of Alberni Harbor and BOD of the Kraft mill effluent. These data and other information provided by the pulp mill companies are gratefully acknowledged.

PHYSICAL CHARACTERISTICS OF THE MARINE ENVIRONMENT

The sea differs basically from fresh-water lakes in its vastness, high salt content, and effect of tides. In estuarine areas, the fact that sea water is quite dense compared to river water has an important bearing on the structure of these waters. Fresh water flowing over the surface of sea water with a relatively high concentration of salt does not completely mix but forms a stable brackish layer. This comparatively fresh water is separated from the deeper sea water by a layer of rapid density change, known as the pycnocline. Because water increases in density with increasing salt content and decreasing temperature, the pycnocline is intensified by a large temperature decrease with depth normally present in summer.

Runoff as it enters the sea flows along the surface of the sea water entraining sea salt at its lower boundary during its seaward movement. This salt is then mixed upward in the brackish surface layer by turbulence. There is virtually no mixing of fresh water downward through the pycnocline, unless intensive mixing by wind or tidal turbulence occurs. To replace the salt removed from the deep seawater layer by entrainment, there must be a net movement of sea water up an estuary below the pycnocline. Theoretically, this must occur in order to maintain a salt balance in the estuarine system so that all the sea water is not ultimately replaced by fresh water. Current measurements in such "two-layered" systems as well as model observations have shown this deep-water, landward flow to actually occur.

The foregoing physical characteristics of an estuary are of considerable importance in waste disposal problems. They point out several factors: (1) Vertical mixing of wastes released at the surface can only occur to any significant degree in the upper layer above the pycnocline. (2) Horizontal mixing in the upper layer can be widespread. (3) Wastes discharged at the surface will experience a continuous seaward flow as a result of the "flushing effect" of the fresh water outflow in the surface layer. (4) Discharge of wastes in the deep landward-flowing seawater layer can lead to intensive pollution in deep water at the head of an estuary. Such a condition may result in pollution near the surface during later years, especially if the deep water is mixed toward the surface by a dredge or some other disturbance.

Besides runoff, the effects of tides and winds are important in the dilution and dispersion of wastes from coastal marine waters of British Columbia. The relative magnitude of these effects varies in the three different marine systems discussed in examples given in subsequent sections.

CHARACTERISTICS OF PULP AND PAPER MILL WASTES

Wastes from the pulp and paper industry can be categorized into three basic groups: (1) Spent sulfite liquor (SSL), (2) Kraft (sulfate) mill effluent (KME) and (3) Groundwood wastes. All the wastes consist basically of fresh water to which have been added various proportions of organic constituents from the wood being pulped, salts used in the digestion process, and fibers which escape into the effluent.

In the sulfite pulping process, a bisulfite cooking solution is added to wood chips, which are digested with heat under pressure for several hours. Depending on the type of base used in the cooking liquor, - calcium, magnesium, or ammonia, - the spent sulfite liquor may be recovered for its salts and organic content or it may be wasted into an adjacent water course. The calcium bisulfite cooking liquor is not amenable to recovery because of various technical problems involved. A magnesium bisulfite cooking process has been developed to a point where recovery is both economical from the pulp mill operation viewpoint and desirable from the pollution prevention viewpoint. Recovery from the ammonium bisulfite process is technically feasible, but it is not economical and is only carried out as a pollution abatement measure.

Spent sulfite liquor consists of a large number of organic constituents, among which the major ones are lignin (about 50%) and hexose and pentose sugars (about 15%). The lignin is relatively inactive and breaks down only slowly in natural waters. However, the sugars contribute to the high BOD (biochemical oxygen demand) of SSL. There are no highly toxic constituents in SSL.

The Kraft process of pulp manufacture is also a chemical technique, where the wood chips are digested at elevated temperature and pressure with a solution containing sodium hydroxide, sodium sulfide, and sodium sulfate as the active ingredients. Following digestion, the "black liquor" is removed from the fibers by a screening process and is then put through a series of evaporators for recovery. The organic constituents are burned in incinerators with a substantial recovery of heat to the plant. The salt content of the black liquor is recovered and recycled for future use. Only those wash waters from the screens, which are too weak for recovery, are passed into the sewer and ultimately into receiving waters. Generally wash waters are also recycled through the screening and washing units. Kraft pulping wastes may exert a toxic and/or oxygen depressing influence on receiving water courses. Combined wastes from a Kraft mill may contain such highly toxic constituents as hydrogen sulfide, mercaptans, resin acids and soaps. Oxygen consuming organic constituents may also be present, but in much smaller concentration than in spent sulfite liquor. It is generally estimated that there is a

ten-fold difference between BOD of Kraft mill effluent and that of spent sulfite liquor.

Groundwood pulp contributes relatively little in the way of chemical pollution of receiving waters. Because groundwood pulp is formed by a purely mechanical process where the wood is reduced to a pulp-like mass by forcing the log against a revolving stone, the main contribution of groundwood pulpeffluent to pollution is in the fibers that escape to the sewer. Some soluble materials from the wood are added to the sewers, but these organic constituents contribute to a relatively small BOD.

Most pulp mills carry out some form of bleaching for brightening their pulp. Bleaching operations involve various stages with the use of sodium hydroxide, sodium hypochlorite, and hypochlorous acid. Other reagents such as hydrogen peroxide and zinc hydrosulfite may be used for specialized bleaching purposes. The effect of bleaching reagents on receiving waters is comparatively small. Usually acidic with some oxidative power, the bleach effluents can partially neutralize the alkaline wastes from the digester section of the pulp mill.

Other wastes, which are mixed in with the foregoing major effluents, include barker wastes, paper machine "white water", evaporator condensates from the Kraft process and general mill sewage. Barker effluents can be rendered virtually harmless by efficient screening. White water from paper machines contains a large amount of fine fibers in suspension which imparts to the effluent its milky appearance. Except by the use of "save-alls", which do not constitute an economic gain for the company, the very fine fibers are difficult to recover.

HOW THE MARINE ENVIRONMENT IS AFFECTED BY PULP MILL WASTES

There are two types of effects of pulp mill wastes in terms of time when they become apparent in the marine environment: A. Immediate and B. Longterm. The immediate effects are those which are manifested in physical and chemical changes of the water immediately after receiving wastes without the later consequences to the bottom, water and biota. A full measure of the immediate effects can be obtained as soon as the inflow of mill wastes and the water system have reached an equilibrium. At that time, there is an equal amount of effluent

being flushed out of the receiving waters to that entering. This balance shifts seasonally as the factors, such as runoff and winds, determining the flushing characteristics of the marine system change.

The long-term effects are those which occur gradually as a result of changes in the ecological conditions incurred by accumulations of certain undesirable materials. This is especially true of the effect of deposition of particulate materials from mill wastes on the bottom. Fibers and other solid mill wastes blanket the bottoms of marine waters and render them unsuitable for development and growth of marine benthic organisms. Populations of bottom-dwelling animals gradually shift from the sensitive species to more tolerant forms, and as conditions deteriorate further, even these forms may not be able to survive.

A. Immediate Effects

1. Chemical changes - inasmuch as most of the waste from pulp mills is chemical in nature, there are important effects which produce chemical alterations in the receiving waters.

(a) Dissolved oxygen concentration - The principal effect of pulp mill waste is the reduction of dissolved oxygen concentration in receiving waters. Two types of oxygen demands are imposed on the water by SSL, - (1) "immediate oxygen demand", which is caused by the chemical reactions between oxygen and reduced sulfur compounds, mainly sulfur dioxide; (2) biochemical oxygen demand (BOD) due to the aerobic decomposition of organic constituents in the receiving water. In ordinary 5-day BOD determinations, the IOD amounts to about 11% of the total oxygen demand (Washington State Pollution Control Commission, MS).

(b) Hydrogen-ion concentration - The introduction of highly alkaline Kraft digester wastes or acidic bleach plant wastes can produce changes in pH of the receiving waters. An indirect effect of pulp mill wastes on the pH of marine waters results from the shift of the bicarbonate - carbonate balance by the liberation of carbon dioxide from the decomposition of the mill wastes. However, sea water has a natural defense against large pH changes because of its high buffering capacity arising out of the presence of weak acid salts, bicarbonates and borates for example.

(c) Increase in other chemical constituents - Large amounts of dissolved organic and inorganic substances, such as lignin sulfonates, calcium salts, and sulfur compounds from SSL; and caustic sodium salts, lignin, mercaptans and resin acids from KME, are added to sea water in pulp mill wastes. This increases the concentration of these constituents in sea water with possible toxic effects on marine organisms.

2. Physical changes - Certain physical properties of the sea water receiving pulp mill wastes are changed as a result of the physical nature of the wastes.

(a) Suspended materials - The suspended load of the wastes may be carried in the receiving waters for some distance but it generally settles out into sludge banks near the outfall. These settled solids contribute mainly to the long-term decay of the system.

(b) Color - The brown effluent contributes to the discoloration of the receiving waters. Secchi disc reading of 25 ft in the clear water of an inlet is reduced to less than 5 ft near an outfall from a sulfite pulp mill. This has a considerable ecological significance in that light penetration is reduced to 1/4 or 1/5 of normal depth, and phytoplankton production suffers accordingly.

(c) Temperature - A temperature rise in receiving waters can result, depending on the volume and temperature of effluent and that of the receiving waters.

Other physical properties undergo changes but are probably less important. For example, surface tension of sea water is lowered by the SSL and much foaming can occur under the action of wind stirring.

B. Long-term effects

The build-up of materials, which settle out from pulp mill wastes, on the bottom of a marine system contributes to a change in bottom ecology. In the inter-tidal zone, the exposed rocks and gravel are often plated over with pitch-like substances from mill wastes making this usually-productive region unsuitable for the settling of invertebrate larvae. Through this adverse effect on the sessile fauna, the food of many fish is eliminated or heavily reduced. Moreover, the reduction of dissolved oxygen by decomposition

of settled organic substances in the bottom material and in the water adjacent to it makes this zone entirely unsuitable for bottom fish.

While a complete change of water in a marine system following cessation of waste input might rapidly restore the original ecological conditions in the water itself, it would probably take a much longer period for the ecological balance between the bottom and the water to be restored. Long-term effects are difficult to assess over short periods. The error is often made in making one or two surveys after a particular polluting source is instituted and assuming that, if conditions are alright then, they will not change thereafter. Monitoring of physical, chemical, and biological conditions should be carried out annually. Changes are very subtle and creep up insidiously.

SULFITE PULP MILL POLLUTION IN NEROUTSOS INLET, B. C.

Neroutsos Inlet is the southeast arm of Quatsino Sound on the northwest side of Vancouver Island (Figure 2). A typically-deep B. C. inlet, it has a relatively small runoff with poor flushing characteristics. At Port Alice, near the head of this inlet, a sulfite pulp mill has been in operation since 1917. It releases its untreated mill wastes at the surface of the inlet, and has created one of the severest cases of marine pollution observed on the B. C. coast. The area was surveyed in August 1957 to study some of the characteristics of sulfite pollution in a marine area and its effect on the fisheries (Waldichuk, 1959).

The salinity and temperature distributions, shown in vertical section in Figure 3, are typical of a B. C. inlet in late summer. The thin layer of brackish water near the surface becomes warmed during the summer giving a large temperature gradient from the surface to 30 ft depth. The combined effect of low salinity and high temperature at the surface produces a large density gradient in the near-surface layer. A large amount of energy is required to mix through this pycnocline, so that under prevailing summer conditions the SSL flows seaward in the surface layer with very little mixing into deep water.

The dissolved oxygen picture, shown in the lower part of Figure 3, is significantly different from that of typical inlet conditions. At the head

of the inlet, there is a large vertical gradient in the surface layer of water with less than 2.5 mg/l at the surface increasing to saturation levels at 20 to 30 ft depth. A decrease occurs again in the deep water to less than 2.5 mg/l. The generally low DO in the bottom water is normally present in most B. C. inlets as a result of slow flushing. Typically of normal inlet conditions, there is a high DO at 15 to 20 ft depth in the water at the entrance to Neroutsos Inlet. This is the result of phytoplankton activity releasing oxygen in their process of photosynthesis. The DO maximum at about 25 ft depth at the head of the inlet may also be caused by a thin layer of phytoplankton, but this has not been substantiated by actual plankton sampling.

Hydrogen-ion distribution through the inlet (Figure 4) follows a similar pattern to the DO with a low pH at the surface in water outside the mill, relatively high values at intermediate depths of 50 to 100 ft and a low pH in deep water. Highest pH levels were measured in the shallow, sub-surface layer at the mouth of the inlet where presumably photosynthesis was high and carbon dioxide was removed from the water.

Spent sulfite liquor is confined mainly to a thin layer of about 25 ft depth at the surface (Figure 4). Concentrations, exceeded 600 ppm at the surface in that part of the inlet adjacent to the pulp mill, and decreased to 30 ppm at a distance of 10 nautical miles from the mill. However, at depths greater than 20 ft, SSL concentration was generally less than 20 ppm even in waters near the pulp mill. Concentrations of less than 10 ppm in the deep water are not considered significant, inasmuch as inshore sea water has substances which respond to the nitrosolignin test (Pearl and Benson, 1940). A "background" value of apparent SSL, can be in the range 0 to 10 ppm. Cells of relatively high SSL appear in the upper 50 ft. These are apparently related to the circulation and mixing process in the inlet.

A small oceanographic survey was conducted by Hutchinson and Lucas (MS) in August 1927. Comparison of their data with those collected in 1957 show some remarkable differences. This is especially true of the dissolved oxygen concentrations observed during the two periods (Figure 5). While the deep water showed similar DO concentrations, the surface and near-surface data were quite different. The very low DO

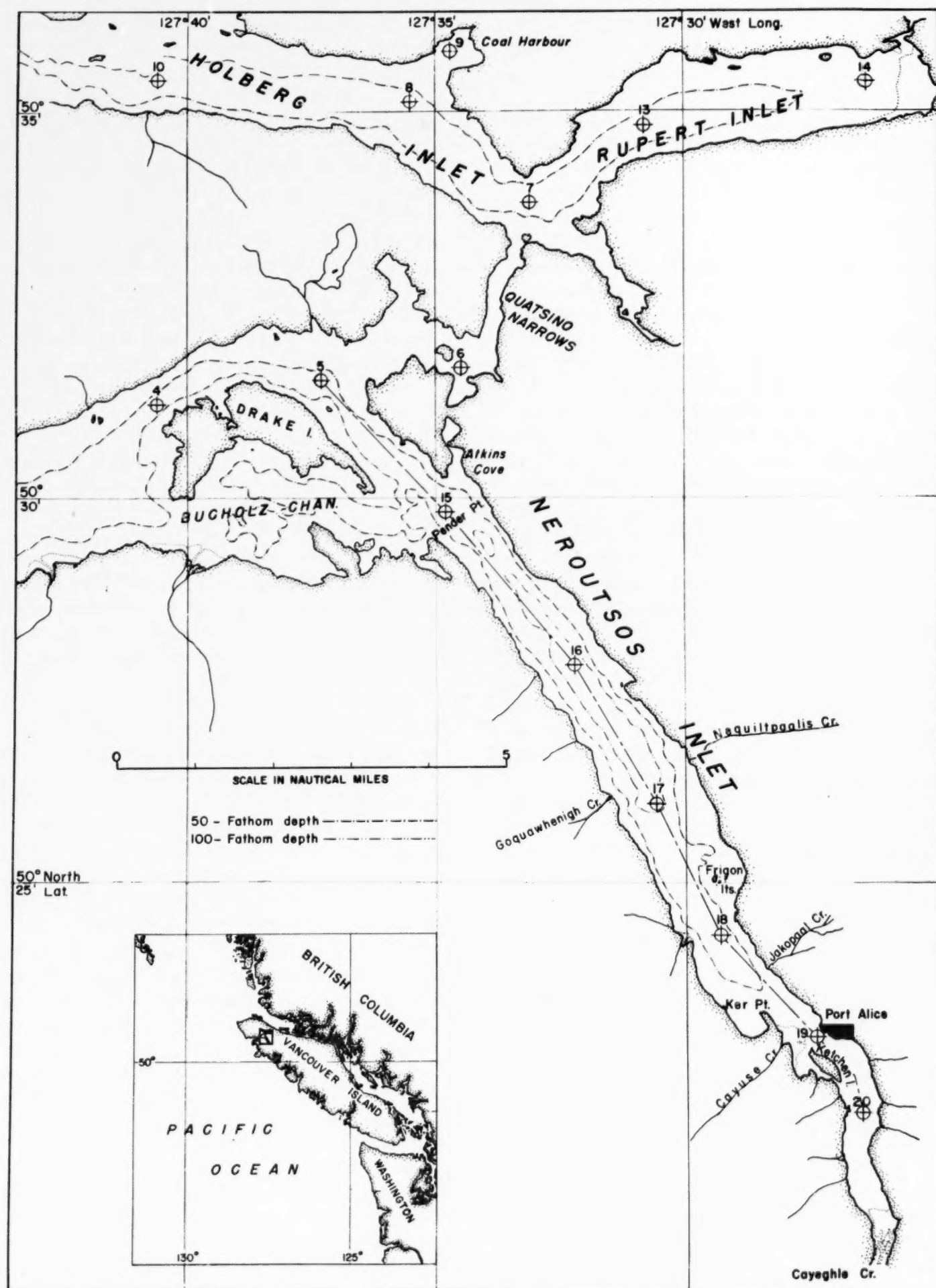


Figure 2. Chart of Neroutsos Inlet in Quatsino Sound with positions of stations occupied 15-19 August 1957.

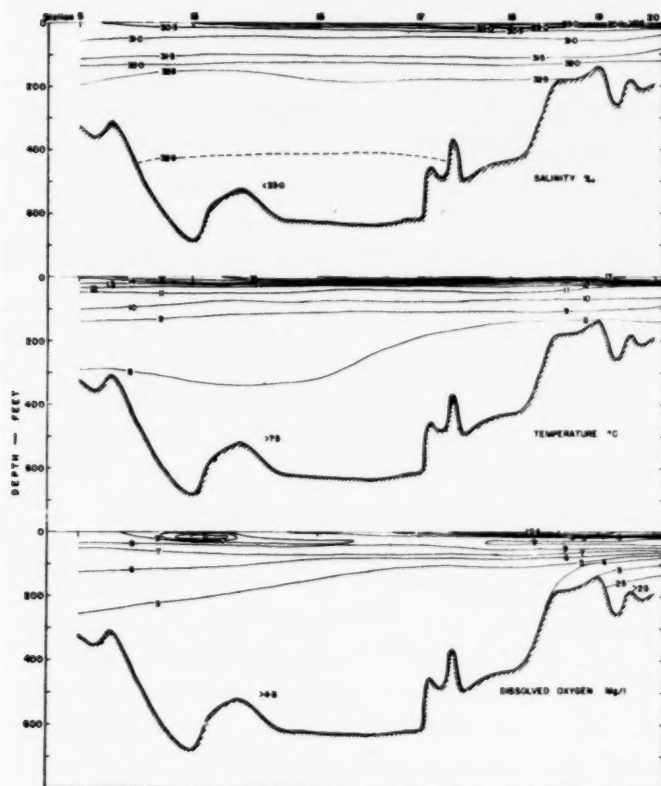


Figure 3. Longitudinal section through Neroutsos Inlet showing the distribution of salinity, temperature and dissolved oxygen.

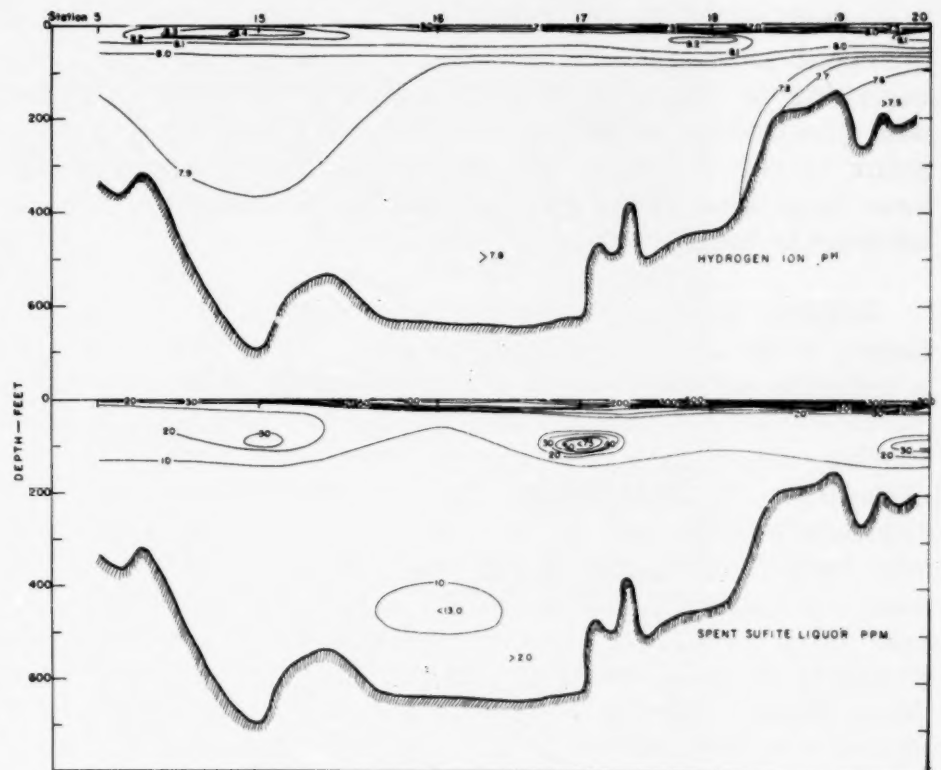


Figure 4. Longitudinal section through Neroutsos Inlet showing the distribution of hydrogen ion concentration and spent sulfite liquor.

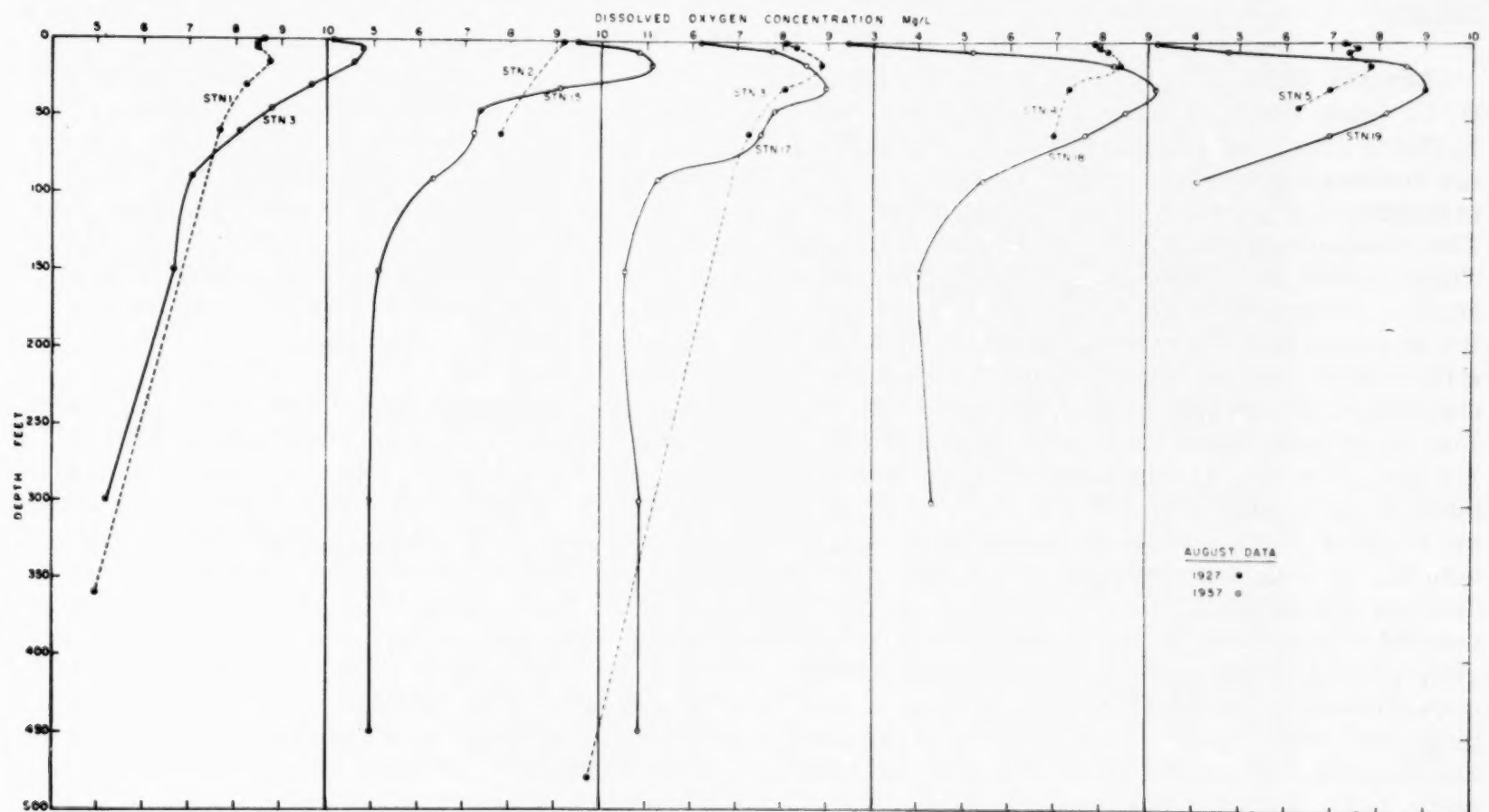


Figure 5. Profiles of dissolved oxygen concentration with depth in Quatsino Sound and Neroutsos Inlet during August 1927 and August 1957.

observed at the head of the inlet in 1957 was absent in 1927. Part of this difference may have been due to lower pulp production during 1927 and dissimilar weather conditions prevailing prior to the two surveys. However, there may have been also a long-term effect on the oxygen balance in the system.

Judging from observations on the aquatic fauna, especially intertidal animals, there was a definite adverse effect on the biota in 1957. Surface water appeared virtually sterile with no fouling organisms on pilings of waterfront structures in Port Alice Harbor. Small fish, commonly observed in the light from the survey vessel during night observations, were absent. In contrast to this, Hutchinson and Lucas concluded in 1927 "(1) That the chemical and physical properties of the water in South East Arm, Quatsino Sound, were well within the limits of sea waters of the continental shelf at the time of this investigation; and (2) that organisms such as are characteristic of similar regions were present there". It would appear that in this inlet, a long-term effect of the 40 years of pulp mill operation had taken place.

KRAFT PULP MILL POLLUTION IN ALBERNI INLET

Alberni Inlet (Figure 6) is another typical B. C. inlet, but it differs from Neroutsos Inlet in that it receives a relatively large runoff from the Somass River at its head. A Kraft pulp mill is located at Port Alberni at the head of the inlet. The oceanography of Alberni Inlet was studied by Tully (1949) as a basis for predicting pollution from a proposed sulfite pulp mill in the inlet. It was shown that the extent of pollution from the mill wastes would depend on the Somass River discharge, which is the chief flushing mechanism. For a relatively small sulfite mill producing 135 tons per day, it was shown that there would need to be a shutdown period of 3-1/2 months every year if intolerable pollution is to be prevented. A possible solution could have been a dam on the Somass River or its tributaries to control the discharge at the required level the year around. The pulp mill company concerned chose to solve this problem by installing a kraft pulp mill instead of a sulfite mill. This mill commenced operation in 1948 and, from then until 1957, it had a modest production of 230 tons per day. During the latter year, expansion was completed to double its production in bleached kraft pulp and commence newsprint

production of about 600 tons per day. This overall production was very near to the threshold level of oxygen supply in the receiving waters. Oceanographic surveys have been conducted in Alberni Inlet following the first five years of pulp mill production in order to evaluate the existing conditions and predict the increase in pollution from expanded production (Waldichuk, 1954; 1956 a). Bioassay on the Kraft mill effluent showed that the maximum safe concentration for 1 week's exposure of young Pacific salmon is 4.8% (Alderdice and Brett, 1957). It was calculated that if sufficient water was available to overcome the oxygen reduction by the BOD of the effluent (Greer, Gillespie and Trussell, 1956) there would be sufficient dilution to overcome the toxicity. Tully's (1949) results were put to use in predicting the level of production which could be sustained without serious pollution. During the early stages of expanded production, the output of pulp had to be juggled with various species yielding low BOD being produced during the low discharge period of late summer. Hydroelectric dams are now being installed on tributary streams to the Somass River so that the water flow into Alberni Harbor can be controlled at a desirable level the year around.

The principle of releasing wastes at the surface into the harbor at some distance from the mouth of the Somass River has been adhered to. Construction of a deep-sea wharf and approach trestle facilitated the installation of a flume to carry the mill effluent to a point as near mid-harbor as practical and into the jet stream from the Somass River. Consequently, stagnation of the effluent in corners of the harbor has been reduced to a minimum.

Salinity, temperature and density distributions (Figure 7) in a section through Alberni Inlet are similar to those of Neroutsos Inlet. There is the typical thin surface layer of low salinity, high temperature and low density. In the shallow harbor area, dissolved oxygen (Figure 8) dropped from surface values of 8 to 9 mg/l to levels less than 5 mg/l at a depth greater than 20 ft. Lowest surface DO was found at points adjacent to the outfall where concentrations of approaching 5 mg/l were noted in August 1957. In deep water, concentrations of DO were between 3.0 and 3.5 mg/l. A low-DO pocket at 400 ft depth near the mouth of the inlet is unrelated to pollution but probably results from decomposition of settled plankton and in-

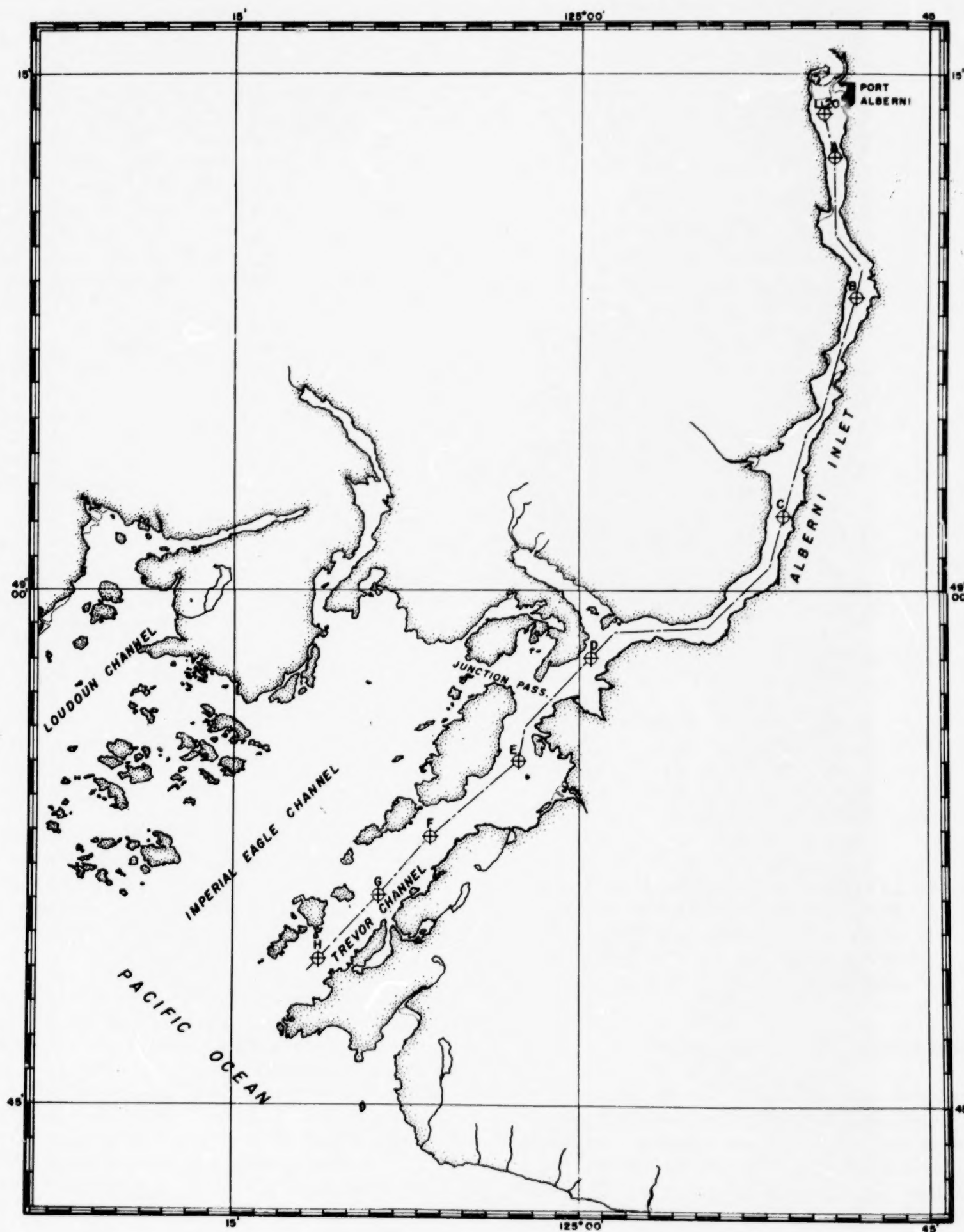


Figure 6. Chart of Alberni Inlet in Barkley Sound showing stations occupied 8-9 September 1954.

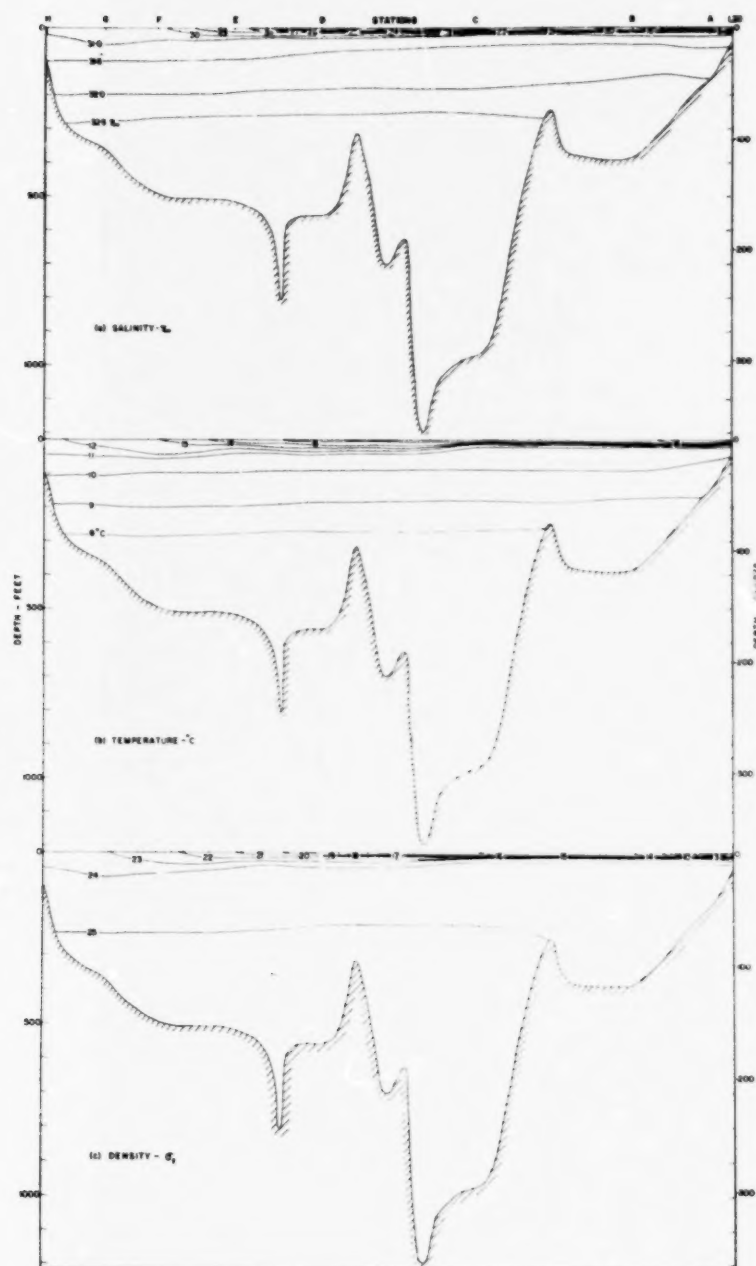


Figure 7. Longitudinal section through Alberni Inlet showing the distribution of salinity, temperature and density (T_t), observed in the September 1954 survey.

frequent flushing (Waldichuk, 1956b).

Seasonal fluctuations in DO at the surface, 10 ft depth and the bottom at mid-harbor are shown in Figure 9. There is a large variation in surface DO from a low of about 5.5 mg/l during August to a high of 13 mg/l in December. Somass River water exhibits DO concentrations only slightly higher than the surface harbor water and undergoes similar week-to-week fluctuations. It was anticipated that the DO of the surface harbor water would be depressed

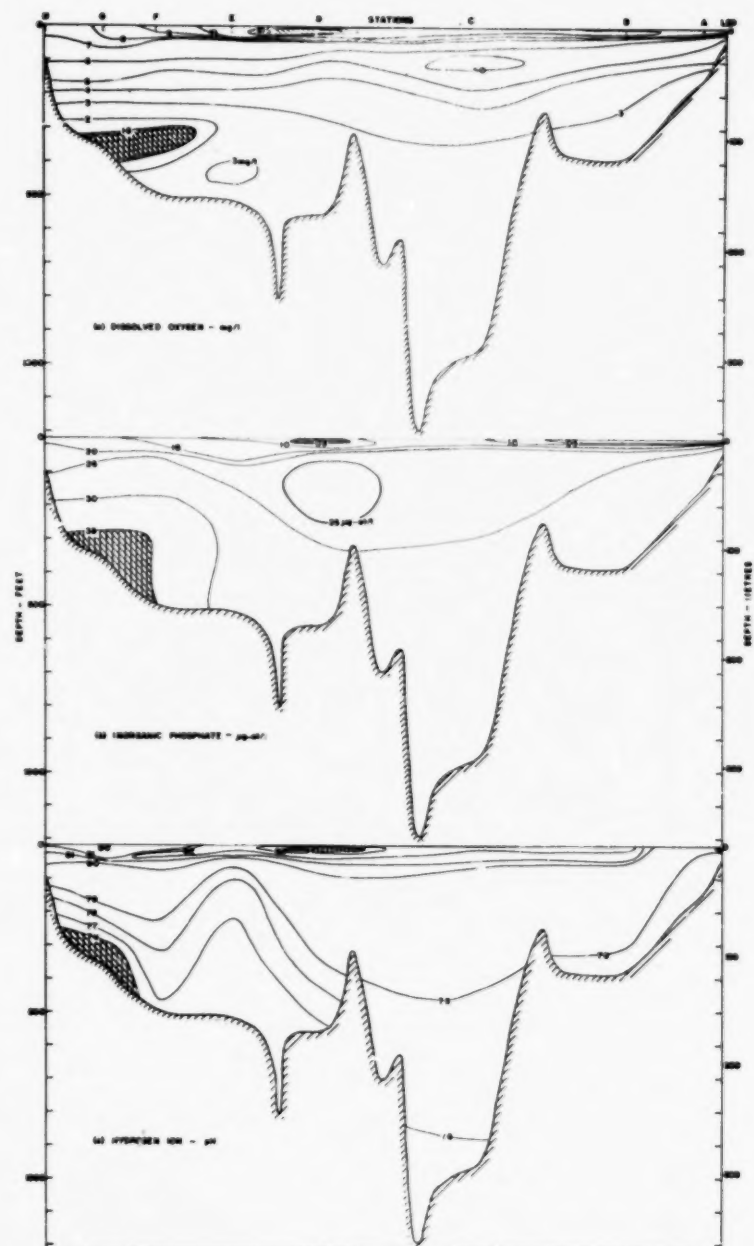


Figure 8. Longitudinal section through Alberni Inlet showing the distribution of dissolved oxygen, inorganic phosphate and hydrogen-ion concentration, observed in the September 1954 survey.

considerably below that of river water during the summer months, but this was not the case, at least for the stations sampled. The region of oxygen sag is probably further down the inlet outside the harbor. This was not observed at stations occupied in the inlet. The wide week-to-week fluctuation of DO observed at 10 ft depth in the harbor is apparently a result of alternation of salt water with fresh water at that depth. During the winter months, the layer of fresh water on the sea surface is quite thick extending, under some circumstances, to a depth greater than 10 ft. This water is saturated with DO at this time. Sea water beneath this layer

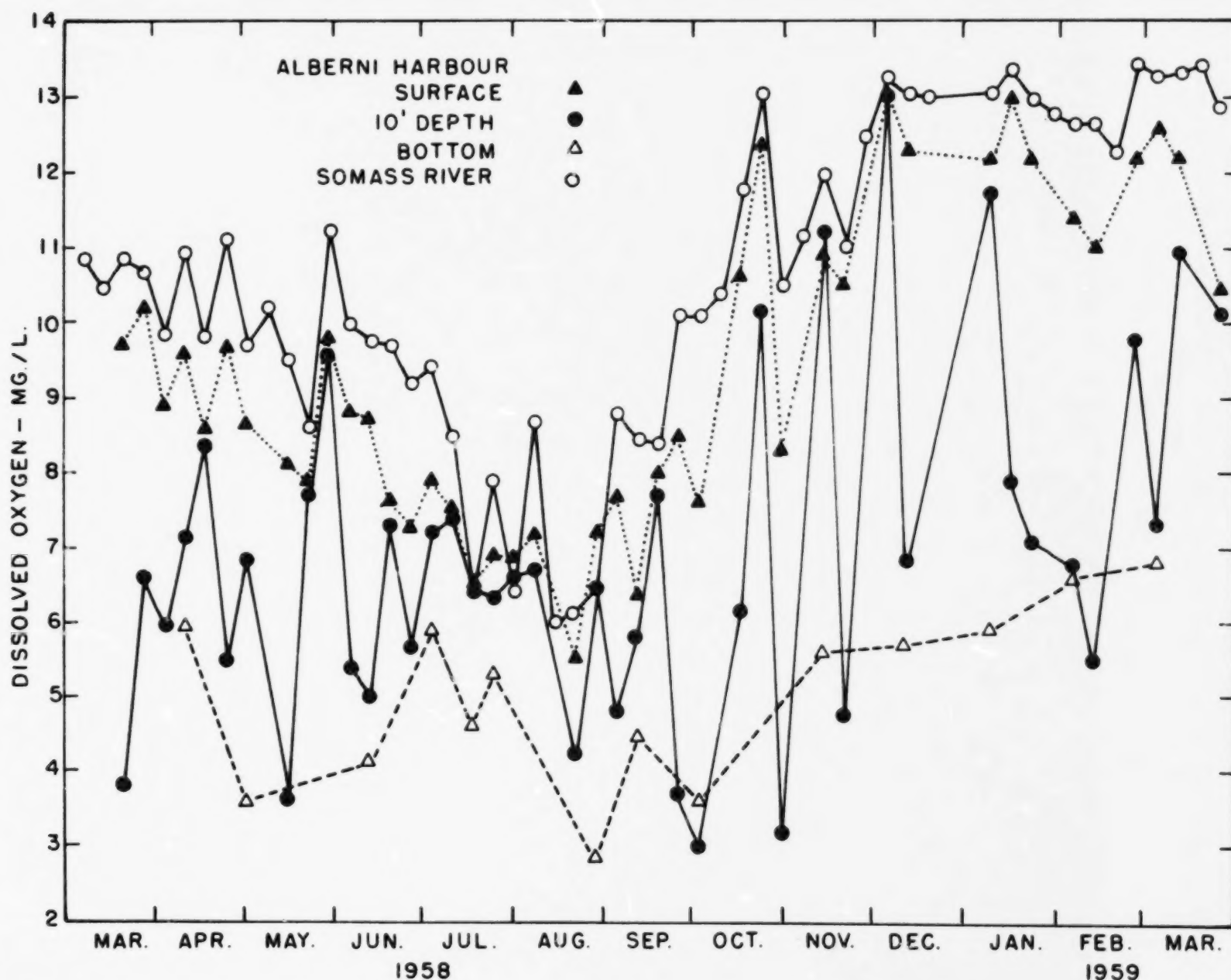


Figure 9. Seasonal variation of dissolved oxygen at various depths in Alberni Harbor (Hohm Island) and in the Somass River, 1958-59.

of fresh and brackish water has a relatively low DO as can be seen from the bottom water concentration at approximately 30 ft depth. Although samples are always taken about 1 hour before daylight high tide, the effect of tide in piling up of fresh water is determined by tidal range which varies considerably from week to week.

Bottom water DO shows smaller fluctuation than that of surface water, but a considerable depression occurs during late summer, with less than 3 mg/l present.

The seasonal picture of BOD of surface water in Alberni Harbor is shown in Figure 10. Some of the large peaks are the result of accidental spillage of black liquor to the sewer or some

other such unusual occurrence. Other peaks may be caused by a high organic content of the Somass River water. Weekly BOD data for the mill effluent are shown superimposed on that for harbor water to note any relationship between the two curves. A few peaks of the two sets of BOD data coincide or the high BOD of water follows that of the effluent by about a week. These relationships may be real or fortuitous.

An apparent long-term effect of wastes in Alberni Harbor is becoming evident in the bottom water. Divers have observed an opaque, milky layer on the bottom in the vicinity of the pulp mill. Its appearance was noted mainly in the log storage area of the northeast part of the

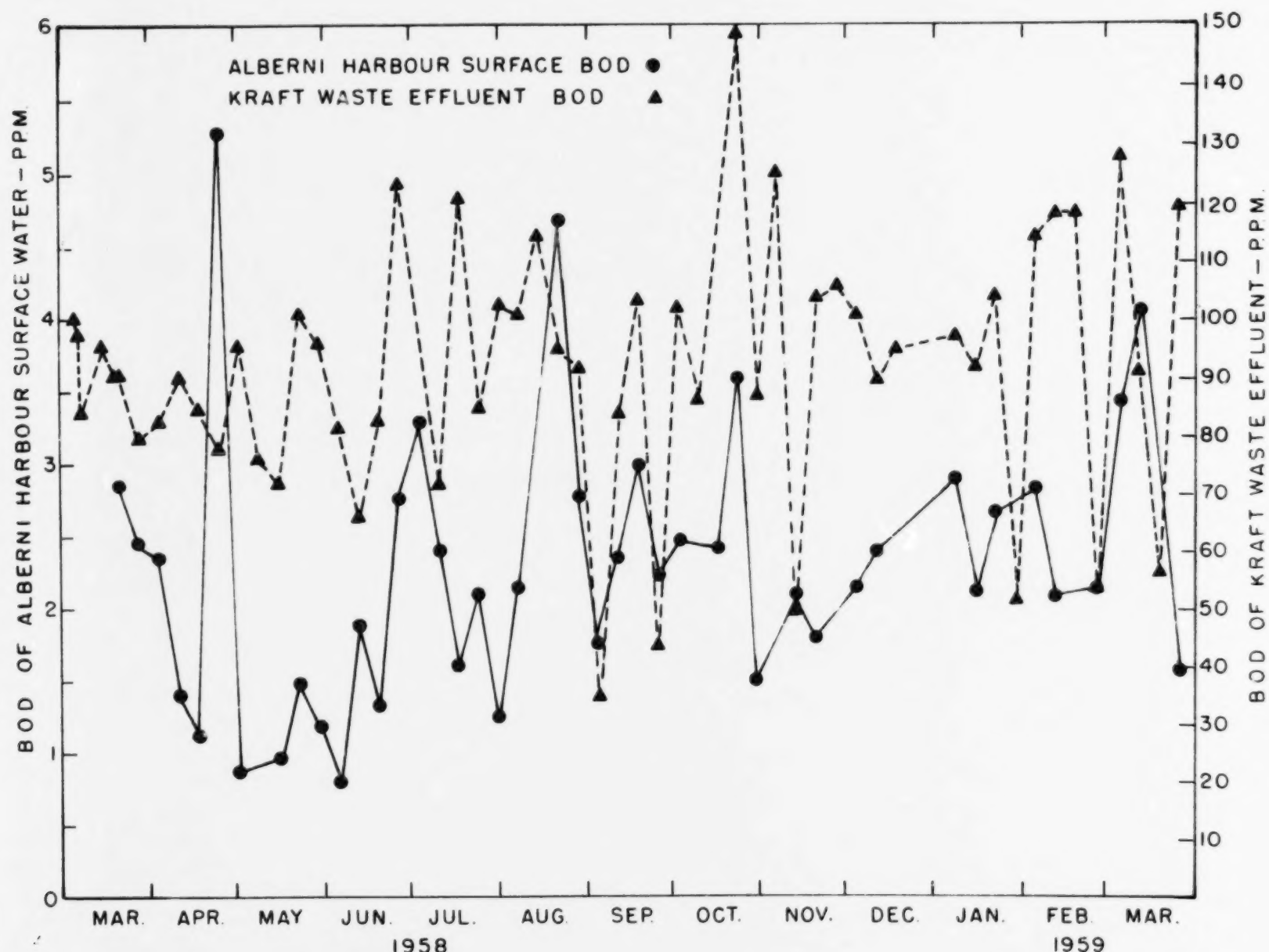


Figure 10. Seasonal variation of BOD of the surface water in Alberni Harbor and of the Kraft waste effluent.

harbor where some stagnation occurs and much solid material settles to the bottom.

Divers have noted bottom fish, described as sea-perch, swimming into the harbor in the clear sea water layer penetrating from the lower part of the inlet at mid-depth. On entering the white layer, the sea-perch apparently suffered no ill effects. However, during low runoff in September, similar fish have been observed to overturn and float to the surface after they were trapped by a large volume of dark brown effluent-containing water moved in by the tide. The turbid layer made log salvage impossible, because of zero visibility, even some weeks after the pulp mill strike of the winter of 1957-58. This suggests that flushing of this deep water

does not occur frequently.

As far as the regular commercial and sport fish are concerned, there has been no obvious reduction in salmon and trout runs up the Somass River system since the pulp mill went into operation. During night-time observations, many small fish could be seen milling around in the illumination cast by deck lights. Small flatfish were observed on the tide flats at the north end of the harbor across the Somass River from the pulp mill. A large kill of sticklebacks and shiners occurred during late September of 1956 when a dredge stirred up the bottom along the dock area of the Port Alberni waterfront (Hourston and Herlinveaux, 1957). This was caused apparently by the stirring up

of oxygen-depleted and hydrogen sulfide-saturated bottom materials. A danger of such an event recurring persists because of the build-up of fibers and other solid refuse from the pulp mill and other establishments discharging wastes into Alberni Harbor.

Alberni Inlet is one region where continuous monitoring must be maintained in order to check on the change in conditions. While predictions can be made reasonably well on the fate and effect of the effluent, the other side effects are more elusive and quantitative evaluations on these are difficult to make. The settling of particulate material has a cumulative effect, which may not appear to be serious in the first year or two of operation but can cause serious complications on a long-term basis.

KRAFT PULP MILL POLLUTION VERSUS OYSTERS IN OSBORN BAY

A pulp mill producing bleached kraft was recently constructed at Crofton, Vancouver Island, on the shores of Osborn Bay (Figure 11). It went into operation early in 1958 and is averaging at present a production of about 550 tons per day.

Osborn Bay falls into the category of restricted embayment. Flushing of the bay is relatively slow; but because of its open connection with a larger body of water, exchange is considerably better than that in an inlet. Circulation of surface water within the bay is dominated by winds. However, outside the bay in Stuart Channel, a fairly strong along-channel tidal flow occurs.

A moderate amount of stratification in water structure exists in Osborn Bay. The salinity at the surface is fairly low as a result of dilution from the nearby Chemainus River (Figure 12). During the summer, surface waters become relatively warm. The density difference between surface and deep water prevents any extensive downward mixing. Consequently, dissolved oxygen concentrations of the deep water become relatively low during the course of a summer.

Oyster leases are formed at the approaches to Osborn Bay. For this reason, the surface waters bathing these oyster grounds must be maintained clean. The principle of allowing pulp mill effluent to flow out on the surface of the sea water is not applicable here, inasmuch as the mechanism for good surface flushing is virtually

absent. It is necessary to obtain the maximum dilution in the shortest possible time followed by adequate dispersion.

The problem of waste disposal from the pulp mill was studied during its earliest inception. (Waldichuk, 1955). A recommendation was made that the effluent be piped into deep water outside the Shoal Islands and there diffused into Stuart Channel. It was calculated that this channel has a sufficiently large volume of water for adequate dilution if the effluent can be dispersed rapidly. By maintaining the effluent discharge away from the inshore circulation, where tidal current sweeps over the tide flats among the islands and an eddy system prevails in the deep water of Osborn Bay the danger of affecting oysters by mill wastes is reduced.

Observations carried out during winter and summer prior to the pulp mill operation (Waldichuk, 1955, 1958) showed that, under average conditions, the flow was along a northwest-southeast direction in Stuart Channel at all points more than 200 yards seaward of the Shoal Islands. Surveys conducted in the area during 1958 after the pulp mill went into operation confirmed the predicted flow of effluent. Only during periods of easterly and northeasterly winds is there a flow of diluted effluent from the diffuser toward the Shoal Island leases or toward Sherard Pt. on Vancouver Island.

The contrast between effluent distribution resulting from its flow over the sea surface and that occurring when proper diffusion takes place was observed during one period in the early stages of production when the pipeline broke and the discharging end lifted to the surface. Flowing over the sea surface in a sharply defined layer, the effluent spread over the channel in a plume following the direction of prevailing flow of tidal current. The main flow was along the axis of the channel, but comparatively high concentrations still reached the oyster leases on the Shoal Islands. Because mixing of sea water and effluent is an irreversible process, there could be no such stratification of effluent on sea water when the diffuser carried out the initial mixing properly. A reduction of density difference between effluent and sea water allows mixing to proceed rapidly by turbulent diffusion.

Dilution of the effluent in the order of 1:280 was noted in August and 1:550 in November between the diffuser and the nearest oyster leases

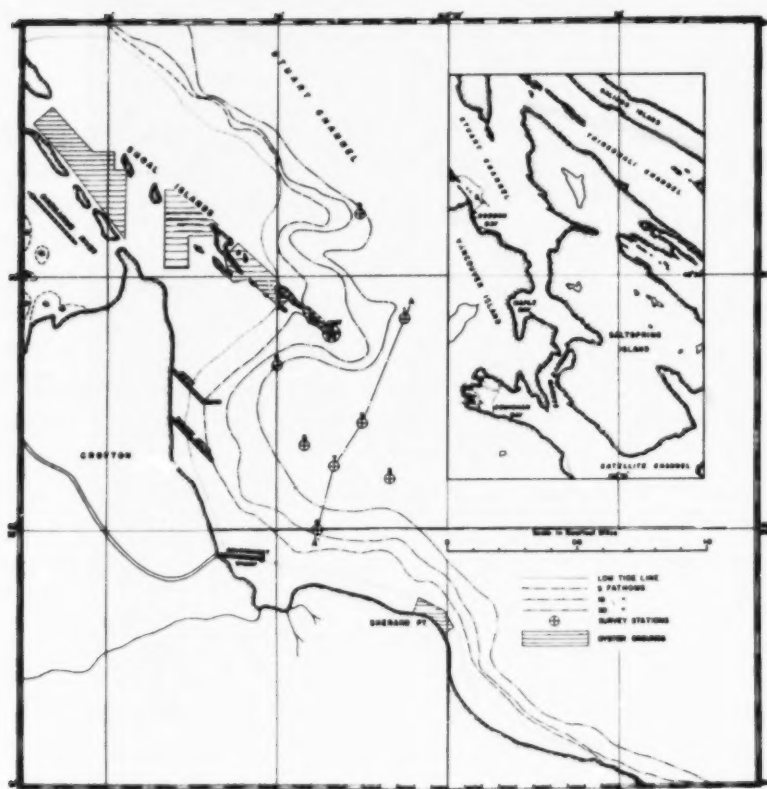


Figure 11. Chart of Osborn Bay showing the location of stations occupied 18-19 November 1954.

1000 yards away. This dilution is 4 to 8 times less than that found to be the minimum required for oysters to be unaffected in research on the York River, Virginia, pollution problem (Galtsoff et al., 1947). The threshold concentration, when the pumping rate of oysters begins to be affected, was estimated to be 1 part of effluent to 2000 parts of sea water in the York River study. However, it is estimated that there has been a 5-fold improvement, and possibly better, in the recovery of kraft wastes during the past two decades.

Dr. D. B. Quayle conducted condition factor studies on oysters in the Crofton area for a number of years prior to pulp mill operation and has recently resumed these studies. Oysters in the area have shown a considerable decline during the winter of 1958-59. Growers believe that this decline has been entirely caused by wastes from the pulp mill. Dr. Quayle's data show that the condition of oysters was low in the whole Stuart Channel region during January and February of 1959. However, his earlier results show that the condition of oysters has been equally low for prolonged periods during previous years. The Pacific oyster (*Crassostrea*

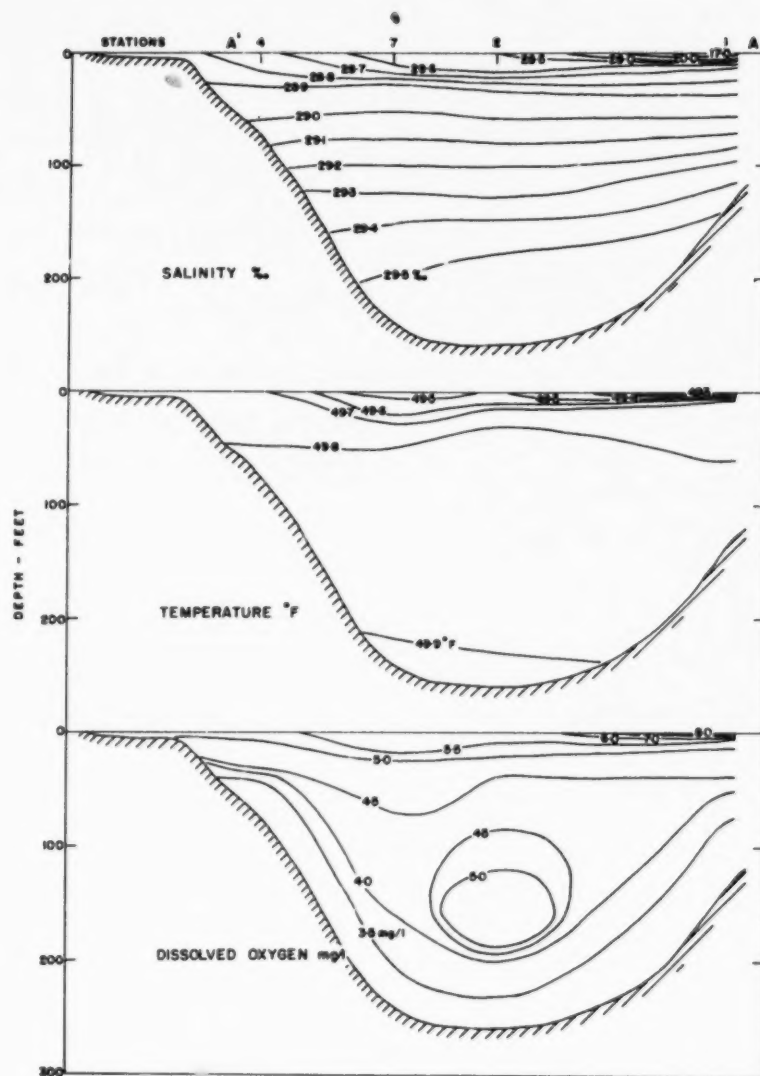


Figure 12. Section through Osborn Bay showing the distribution of salinity, temperature and dissolved oxygen, observed in the November 1954 survey.

gigas) spawned heavily during the summer of 1958 when sea water temperatures were unusually high. The question has been raised as to whether the oysters fully recovered from the 1958 spawning and whether subsequent feeding conditions were so poor as to prevent the oysters from fattening properly. Field experiments being conducted by Dr. Quayle this spring should provide some information on how oysters are affected by the Kraft Mill effluent at different distances from the outfall, i. e., by different KME concentrations.

The ideal marine location for a pulp mill pollution-wise is the shore of a tide-swept, turbulent channel. An example of such a location in British Columbia is on the shores of Discovery Passage, a narrow channel between northern Vancouver Island and the mainland. A kraft pulp and newsprint mill in Duncan Bay

(Figure 13) discharges its wastes into the swift and turbulent waters of Discovery Passage. As shown in Figure 14, the distribution of salinity, temperature, and dissolved oxygen from top to bottom in this passage is almost homogeneous. The lens of relatively low salinity, high temperature, and high dissolved oxygen in mid channel was probably moved in by tidal currents from a stratified area outside the channel and had not yet been dissipated. Effluent cannot be detected

by our available analytical methods outside a radius of a few hundred yards from the outfall.

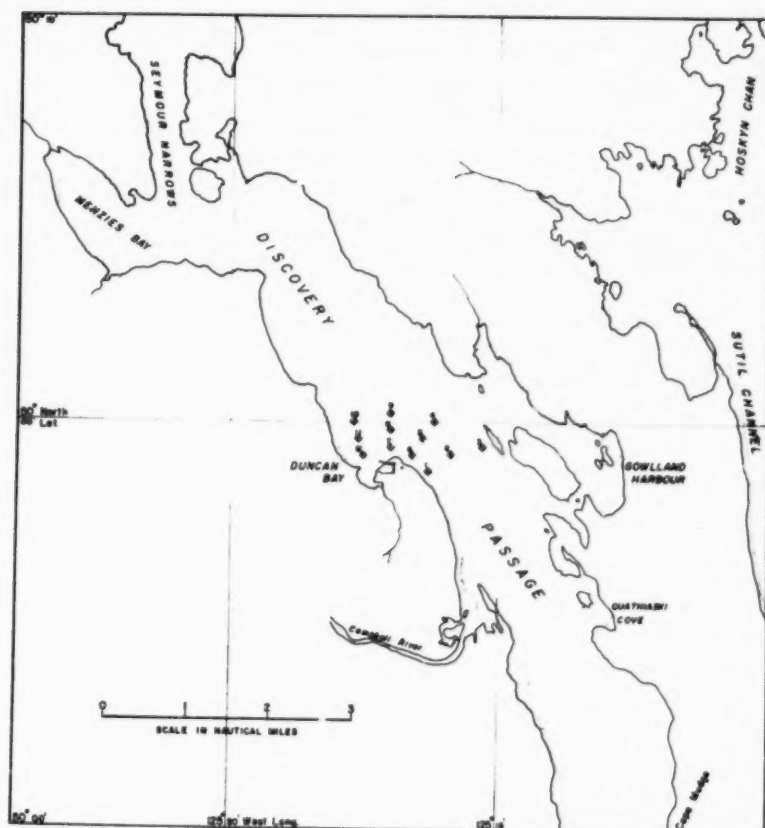


Figure 13. Chart of Discovery Passage showing location of stations occupied 3-4 July, 1957.

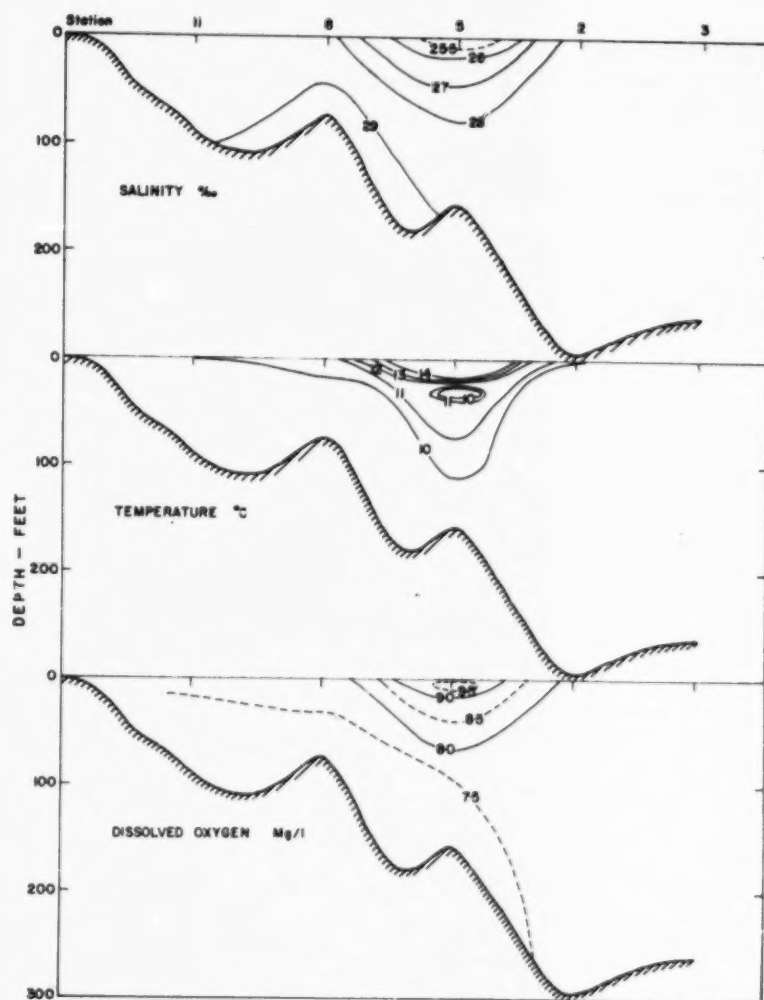


Figure 14. Section across Discovery Passage and through Duncan Bay showing distribution of salinity, temperature and dissolved oxygen, observed during the July 1957 survey.

REFERENCES

Alderdice, D. F. and J. R. Brett. 1957. Some effects of Kraft mill effluent on young Pacific Salmon. *J. Fish. Res. Bd. Canada*, 14(5): 783-795.

Galtsoff, P. S., W. A. Chipmann, Jr., J. B. Engle and H. N. Calderwood. 1947. Ecological and physiological studies of the effect of sulfate pulp mill wastes on oysters in the York River, Virginia. *U. S. Fish and Wildlife Service, Fishery Bull. Fish and Wildlife Service*, 51, Bull. 43:59-186.

Greer, B. A., R. E. Gillespie and P. C. Trussell. 1956. Biochemical oxygen demand of full-bleach Kraft mill effluent determined by dilution with sea-water and standard dilution water. *TAPPI*, 39(8): 599-603.

Hourston, A. S. and R. H. Herlinveaux. 1957. A "mass mortality" of fish in Alberni Harbor, B. C. *Fish. Res. Bd. Canada, Pacific Prog. Rep. No. 109*: 3-8.

Hutchinson, A. H. and C. C. Lucas. MS. Report on the waters of Quatsino Sound, Alice Arm, the effect of the pulp mill at Port Alice, 1927. *MS Report of Biological Stations*, No. 324: 9 pp.

Pearl, I. A. and H. K. Benson. 1940. A nitrosolignin test for sulfite waste liquor in sea water. *Paper Trade Journal*, III(18): 35-36.

REFERENCES (Cont' d.)

Tully, J. P. 1949. Oceanography and prediction of pulp mill pollution in Alberni Inlet. Fish. Res. Bd. Canada, Bull. No. 83: 169 pp.

Waldichuk, Michael. 1954. Effect of pulp mill waste in Alberni Harbor. Fish. Res. Bd. Canada, Pacific Prog. Rep. No. 101: 23-26.

_____. 1955. Effluent disposal from the proposed pulp mill at Crofton, B. C. Ibid., No. 102: 6-9.

_____. 1956 a. Pulp mill pollution in Alberni Harbor, British Columbia. Sewage and Industrial Wastes, 28(2): 199-205.

_____. 1956 b. Basic productivity of Trevor Channel and Alberni Inlet from chemical measurements. J. Fish. Res. Bd. Canada, 13(1): 7-20.

_____. 1958. Summer oceanography in Osborn Bay, B. C. Fish. Res. Bd. Canada, Pacific Prog. Rep. No. 110: 6-12.

_____. 1959. Some oceanographic characteristics of a polluted inlet in British Columbia. J. Mar. Res. (In press).

Washington State Pollution Control Commission. MS. Composition of sulfite waste liquor from sulfite pulping processes. 3 pp.

MARINE POLLUTION PROBLEMS IN THE SOUTHERN CALIFORNIA AREA

Claude E. ZoBell - Professor of Microbiology & Chairman Marine Biology Division
Scripps Institution of Oceanography, University of California, La Jolla

ABSTRACT

More than a billion gallons of sewage is discharged daily into the ocean along the coast of California. Nearly two-thirds of this finds its way into the sea in a few highly localized areas in the southern part of the State. Those charged with the responsibility of sewage disposal have experienced difficulty in keeping pace with the rapid and unanticipated increase in population--nearly 4% gain per year during the last decade. Nevertheless, engineers and health authorities alike are dedicated to the proposition that sewage should neither jeopardize human health nor unduly destroy natural resources. The latter include harvestible seaweeds, fish and other marine fauna, and beneficial uses of beaches, bays and sea water.

The beneficial uses include swimming, skin diving, surf boarding, fishing, boating, aesthetic enjoyment, commercial shipping, naval vessels, and water for industrial cooling, cleaning, fluming, flushing, etc. Though difficult to assess in terms of dollars, some people place the premium upon aesthetic values--the sense of satisfaction derived from seeing and smelling good, clean, clear, blue sea water. It seems, though, that part of the price to be paid for the privilege of living in populous areas on the sea coast is the modification of adjacent waters. Not only does sewage itself contribute to the discoloration of sea water, it promotes the growth of plankton organisms. However, the health and economy of populous communities must be protected.

The California State Pollution Control Board recommends that the concentration of coliform bacteria shall not exceed 10 per ml in water from recreational beaches or bays. Certain coastal communities have experienced difficulty in complying with this standard of sanitation owing to rapid population increases, mechanical failures of sew-

age processing plants or pipelines, adverse meteorological or oceanographic conditions, and the prolonged survival of coliform bacteria in the sea.

Remote from the influences of man, bacteria of sanitary significance do not appear to be normal inhabitants of the sea. Only small numbers of such bacteria were found in 103 out of 2,167 samples of sea water and bottom deposits collected at stations many miles from land. Even here, man may have been responsible for the occurrence of such bacteria. They occur commonly and abundantly, however, in coastal waters and bottom deposits in the vicinity of sewage outfalls and around ships in harbors. From a few to nearly a million coliform bacteria per ml. have been demonstrated in bottom deposits collected within a radius of 5 to 10 miles of submarine sewage outfalls and in bays.

Following sewage fields at sea with dye patches and with radioactive tracers (scandium-46) while determining the abundance of coliform bacteria, it has been found that the T-90 of such bacteria ranges from 2 to 20 hours, the average range being 3 to 8 hours. T-90 is the time required for a 90% reduction in the number of coliform bacteria detected by Standard Methods. Under laboratory conditions, the T-90 of coliform bacteria suspended in sea water ranges from 10 to 100 hours. This shows that forces or factors are operative under natural conditions in the sea that are not revealed by laboratory observations alone. Most important of these factors are dilution or dispersion of the sewage bacteria in sea water, aggregation or flocculation of bacteria into clumps, sedimentation, and predation. In progress are monitoring and research programs designed to determine the effects of domestic and industrial wastes on marine plant and animal life.

The daily discharge of sewage into the ocean along the coast of California exceeds a billion gallons (Pearson, 1956). Nearly two-thirds of this finds its way into the sea in a few highly localized areas in the southern part of the State. The City of Los Angeles discharges about 300 million gallons per day into Santa Monica Bay. Los Angeles County outfalls carry somewhat more than 250 million gallons per day into San Pedro Channel. San Diego Bay receives nearly 45 million gallons per day. Santa Barbara and

Orange County each dump about 25 million gallons per day into coastal waters.

The southern California sewage problem is unique in several ways. First, there is virtually no natural runoff along the coast to provide for the dispersion or dilution of the sewage. The average annual rainfall ranges from 10 to 20 inches, most of which falls during the winter months. Since as much water as practical is impounded in storage reservoirs, only rarely do

the rivers carry much into the sea. Either raw, primary or secondary-treated, and/or chlorinated sewage is carried into the sea by submarine outfalls ranging from a few hundred feet to a few miles in length.

More than 90 percent of the southern California population is concentrated in little pockets along the coast, from which foothills or high mountains rise precipitously. Thus proposals for pumping the watery wastes inland for disposal are generally discouraged by the added expense of elevating the sewage several hundred to a few thousand feet.

In the interests of current economy and guided by precedent, most sanitary districts in southern California gather domestic wastes from rather extensive geographic areas for treatment in central plants and disposal at sea. While this may be more economical than constructing numerous smaller plants and ocean outfalls, bringing the sewage to a central plant does pose the problem of dispersing the effluent safely in the sea near the place where the population pattern is densest.

Another unique feature of the sewage problem is the rapid and unanticipated population increase in California, --nearly 4 percent gain per year during the last decade. As a result, certain sewage disposal systems have become obsolete or inadequate more rapidly than they can be designed, financed, and constructed. Unlike older populous centers along the east coast of U. S. A. or in western Europe, where sewage has been discharged into the sea for centuries, the pollution problem in southern California has become increasingly more acute only relatively recently. Engineers and health authorities alike are dedicated to the proposition that the effluent should neither jeopardize human health nor unduly destroy natural resources.

BENEFICIAL USES OF COASTAL WATERS

In San Diego and in San Pedro harbors, large volumes of sea water are used for fluming and thawing fish in the vicinity of canneries and for flushing fish wells aboard fishing vessels. Seaweed processing plants use millions of gallons of bay water per day for washing, leaching, and fluming chopped kelp. Reduction companies make use of bay water for converting fish and other animal wastes into various products. One of the largest marine salterns in the world ob-

tains salt by the evaporation of water from upper San Diego Bay. Power and electric companies use tremendous volumes of sea water for cooling condensers in steam plants. In most of these as well as in other commercial applications, there is concern for the corrosive and toxic characteristics of sea water and also for sanitation, which may be aggravated by domestic and industrial wastes dumped into the sea.

Thousands of fishing, military, and commercial vessels of many types make use of coastal harbors and bays every month. Many such vessels make extensive use of sea water for cooling and flushing purposes. As one of the major U. S. Naval harbors on the West Coast, the floating population on San Diego Bay alone often exceeds 25,000 persons. Many more people use beaches, bays, and coastal waters for boating, bathing, fishing, clamming, skin-diving, surfboarding, aquaplaning, and other recreational pursuits.

Some people place the premium upon aesthetic values, --the sense of satisfaction derived from seeing and smelling good, clean, blue sea water. It seems, though, that part of the price one must pay for the privilege of living on the coast is having nearby waters discolored as a result of so many people being there. The health and economy of the community must be protected.

PUBLIC HEALTH ASPECTS OF PROBLEM

The California State Water Pollution Control Board recommends that the density of coliform bacteria shall not exceed 10 per ml. in excess of 20 percent of the samples taken along recreational beaches. The maximum allowable limit is 100 per ml. beyond the 1500-ft. line, exclusive of certain defined areas near the sludge or effluent outlets, which for most sanitary districts are located several thousand feet from shore (Figure 1).

Most of the time the concentration of coliform bacteria is well below the prescribed limits. Occasionally, however, mechanical failures or a combination of adverse meteorological, hydrographic, and hydrodynamic conditions have resulted in excessive concentrations of coliform bacteria on beaches in the surf zone. In some cases the affected beach areas have been quarantined, or the effluent has been chlorinated to safeguard human health. Considerable oceanographic, bacteriological, and engineering research work has been directed towards trying

to find ways of precluding possibilities of even temporary pollution of coastal areas (California State, 1943; Hartmen, 1956; Gunnerson, 1958; Rittenberg, 1956; Rittenberg, *et al.*, 1958).

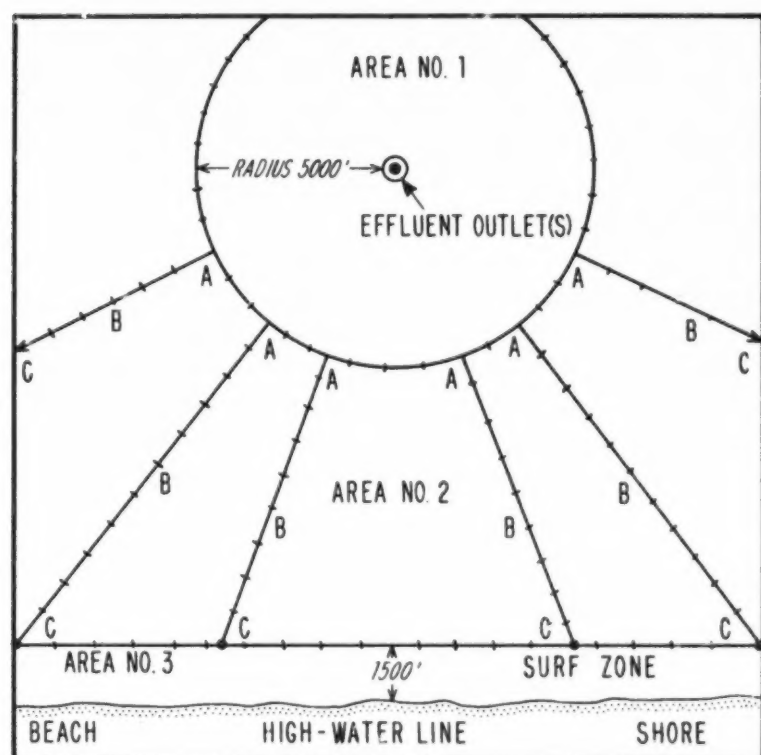


Figure 1. MPN of coliform bacteria shall not exceed 10 per ml. in any three consecutive samples or in more than 20% of any 20 consecutive samples in Area No. 3 (shoreline stations); 100 per ml. for Area No. 2 (samples taken along 8 "B" and "C" traverses).

SURVIVAL OF COLIFORM BACTERIA IN THE SEA

An important desideratum is the natural occurrence and fate of coliform bacteria in the sea. During the last two decades we have collected for bacterial analyses several thousand samples of sea water, bottom deposits, and plankton hauls from the Pacific Ocean. The production of acid and gas in lactose broth was taken as presumptive evidence for the presence of coliform bacteria, as outlined by Standard Methods (A.P.H.A., 1955). Positive cultures were enriched in brilliant green lactose broth and confirmed on eosin methylene blue agar. From finding few or no coliform bacteria in marine materials collected at places remote from possibilities of terrigenous or human con-

tamination, it appears that *Escherichia coli* and allied enteric forms are not normally marine. This conclusion is based upon observations as follows:

Total tests	Kind of marine material examined	Total number positive		
		0.1 ml.	1.0 ml.	10 ml.
1,468	Sea water collected from open ocean	3	12	43
585	Bottom deposits from open ocean stations . .	0	5	40
114	Plankton hauls from open ocean	0	0	3
630	Intestinal contents of marine fish	42	206	474
9	Intestinal contents of marine mammals . . .	0	2	4
61	Intestinal contents of marine birds	11	21	39
3,850	Sea water collected near shore	248	693	1,388
968	Bottom deposits from near shore areas	36	83	260
114	Shellfish collected from near shore areas	9	25	82

Less than 1 percent of the samples of open ocean materials gave positive presumptive tests; the presence of *E. coli* was confirmed in none. That such enteric bacteria do occur in marine materials, though, is indicated by positive results with numerous samples from fish, sea lions, and shellfish as well as sea water and bottom deposits collected near shore. Only 9 percent of the lactose-fermenting enrichment cultures from the intestinal contents of marine animals were found to contain *E. coli*, approximately 75 percent of the gas-producers being *Aerogenes* species. The circumstances suggest that *E. coli* is not normally an inhabitant of the gut of marine fish, sea lions, or sea gulls. Those having appreciable numbers of coliform bacteria may have been feeding recently in polluted waters. The period of time that *E. coli* and allied enteric organisms may remain viable in the gut of marine animals has yet to be determined.

Coliform bacteria concentrations as high as 10^3 to 10^5 per ml of water or mud have been found in the vicinity of certain ocean outfalls. Rittenberg *et al.*, (1958) found coliform bacteria as follows around three marine sewage outfalls:

Location of Outfall	Total samples	Number positive	Range of MPN coliforms/cm ²
Orange County . .	100	83	nil to 25,000
White's Point . . .	106	72	nil to 92,000
Santa Monica Bay	109	9	nil to 250

Although such concentrations occur mostly within a radius of a few thousand feet of the sewage effluent or sludge outlets, large numbers of coliform bacteria have been found in water as well as in bottom deposits 5 to 10 miles from the nearest outlet.

In view of the vast numbers of coliform bacterial discharged into the sea with domestic sewage, it is hardly surprising to find such bacteria in the vicinity of boat harbors and sewage outfalls. California sewage contributes an estimated 2×10^{18} coliform bacteria per day. If evenly distributed in all offshore water on the continental shelf to a depth of 100 meters, this would create a coliform concentration of approximately 50 per ml. Such bacteria are found, though, only within a radius of a few miles of place where they were introduced. Their paucity or absence from remote regions is indicative of the relatively rapid rate at which coliform bacteria disappear from the sea.

The survival of coliform bacteria in the sea is influenced by a multiplicity of interrelated factors (Beard and Meadowcroft, 1935; Greenberg, 1956; Nusbaum and Garver, 1955; Orlob, 1956; Vaccaro et al., 1950; Weiss, 1951; ZoBell, 1936; 1946). While laboratory investigations on the effects of salinity or mineral content, kind and concentration of organic matter, temperature, age, and abundance of coliform bacteria in sea water suggest a T-90 ranging from 10 to 100 hours, field observations indicate a much more rapid disappearance. This is probably because sedimentation, dilution, flocculation, aggregation, adsorption, predation, antibiosis, antagonism, phage, sunlight, and other mechanisms, ordinarily not operative in test tube experiments, contribute substantially to the disappearance of coliform bacteria in the sea (Figure 2). The T-90, or time required for a 90 percent reduction in the MPN of coliform bacteria, ranges from 2 to 20 hours in the sea near different outfalls; the average range being 3 to 8 hours.

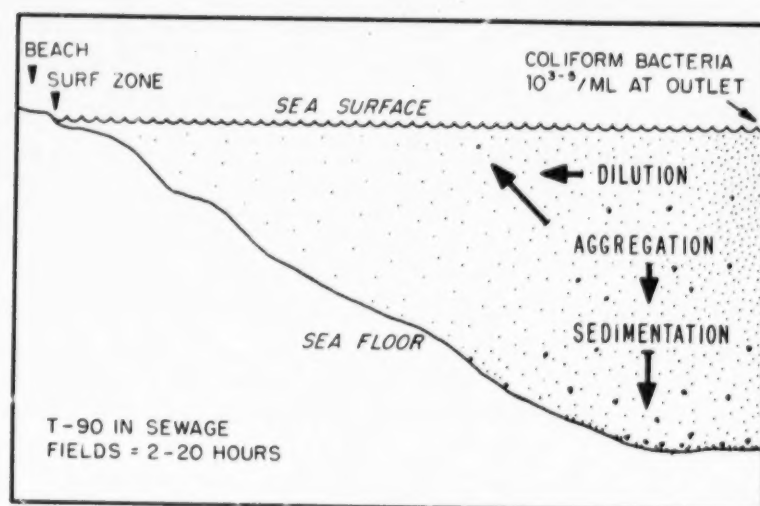


Figure 2. Dilution, aggregation, sedimentation, and predation are believed to be most important factors responsible for decrease in the MPN of coliform bacteria around outlets of sewage outfalls in the sea where average T-90 values range from 2-20 hours, as compared with average T-90 values of 10-100 in sea water under laboratory conditions. Buoyant aggregates may float to surface of sea and be washed ashore.

By following the shoreward movement of sewage fields with dye patches and with radioactive tracers (scandium-46) while determining the MPN of coliform bacteria, Rittenberg (1956) estimated the average T-90 for Hyperion primary effluent in Santa Monica Bay to be about 3 hours for the first few hours after discharge. This value is in good agreement with a T-90 value of 3.4 hours reported by Gunnerson (1958), who found a T-90 of 6.5 hours for Hyperion secondary effluent. Nine hours after discharge of the sewage, the T-90 increased to about 15 hours. This sharp increase may be a reflection of the greater resistance of bacteria that had already survived in the sea for several hours, or it may be an anomaly in the surf zone caused either by disaggregation of bacterial clumps or by the more rapid movement of bacteria shoreward in the surface film of water.

The rather rapid initial decrease in concentration of coliform bacteria after being discharged into the sea is believed to be attributable primarily to dilution, sedimentation, and aggregation or flocculation. Needed is more information on the fate of such bacteria in sediments and aggregates. Do the majority of bacteria in

aggregates or clumps die off rapidly or may they be protected long enough to wash ashore to be disaggregated or broken apart in the surf zone, where viable enteric organisms may be of public health significance?

The occurrence and disaggregation of clumps of coliform bacteria in sea water has been demonstrated by laboratory experiments. For example, treating mixtures of sewage and sea water with 10 p.p.m. Tween 80, a dispersing agent, resulted in MPN's that were from 1.7 to 3.9 times higher than untreated controls. Similarly, 10 seconds' treatment in a Waring blender increased the MPN's of such mixtures by as much as fourfold after different periods of storage. Prolonged agitation, as in the Waring blender, or prolonged treatment with dispersing agents decreased the MPN's, ostensibly because dispersed cells are more vulnerable to adversity than those in clumps or aggregates.

There is some evidence that the bacterial population in the surface film of water may be considerably larger per unit volume than in the underlying water. Technical difficulties of skimming off surface film for analysis have hampered attempts to obtain accurate estimates. The surface film is the uppermost one-millionth to one-tenth of an inch (Ewing, 1950). Certain bacteria appear to be concentrated in the surface film of water (1) by its surface tension, (2) by the low specific gravity of the bacteria, and (3) by the buoyancy of lipids or gases with which the bacteria are associated. Horrer (1956) gives four reasons why the surface film may be of public health importance:

- (1) Bacteria tend to concentrate there.
- (2) The film moves with the wind at speeds in excess of measured ocean currents.
- (3) Internal waves, wind, and currents cause horizontal compaction (and thus concentration) of materials in the surface film.
- (4) Dispersion or diffusion of these surface film materials in the underlying water appear to be surprisingly small.

ECONOMIC ASPECTS OF POLLUTION

Much more controversial than standards of sanitation required to safeguard human health are the effects of sewage on marine resources;

aesthetic values in particular. Small quantities of sewage, properly dispersed in the sea, may actually be beneficial for marine plants and animals of economic significance. Excessive amounts may adversely affect food chains, seaweeds, fin fish, shellfish, and other animals in localized areas. The discoloration of water, the appearance of floating solids or debris of sewage origin in the water or on beaches, the presence of grease or oil slicks, and the occurrence of offensive odors constitute nuisances or unaesthetic conditions. Those charged with the responsibility of disposing of sewage attempt to minimize objectionable conditions by adequate sewage treatment (screening, skimming, settling, holding, etc.) and by discharging the effluent or sludge as far from beaches and as dispersed as is economically practical.

Offensive odors and unsightly objects in the water or on beaches have been largely eliminated in most sanitation districts. More troublesome is discoloration of water. Experiences at Hyperion indicate that adequate treatment of sewage and discharging the sludge in submarine outfalls can minimize turbidity. Nutrient-rich effluents may not initiate plankton blooms (Stephenson and Grady, 1956), but they may promote the growth of plankton. Greatly increased numbers of phytoplankton at certain times of the year increase the turbidity of water and decrease its transparency within a radius of a few miles of certain sewage outfalls in the southern California area.

Although neither the mechanism nor the extent of injury has been established, there is some evidence to suggest that kelp beds (*Macrocystis pyrifera*) of commercial importance may have been adversely affected by discharged wastes. Several different postulates have been advanced to account for the damage: (1) Increased turbidity may restrict the development of young kelp plants on the sea floor at depths of 30 to 90 feet below the water surface. (2) Either reduced oxygen tension or slime formation at the mud-water interface may inhibit the development of kelp sporophytes. (3) Detergents or other toxic ingredients in sewage may be harmful to kelp. (4) Organic substances in sewage may render the seaweeds more vulnerable to invasion by infectious microbes.

There is no direct evidence for adverse effects of sewage on fish in the vicinity of ocean outfalls, despite claims to the contrary by

adversaries of sewage disposal at sea. Certain bottom-dwelling forms, including flatfish, abalone, and crabs, seem to have disappeared in places, but it has not been ascertained whether pollution, overfishing, or other factors have been responsible. Nevertheless, most citizens view with considerable concern what effect the continued discharge of increasing amounts of domestic and industrial wastes may have on aquatic life. Hartman (1956) has indicated some of the changes in size, abundance, and kinds of species of bottom fauna that occur in the neighborhood of the Hyperion outfall.

Underway are various long-range programs designed to obtain information that may be use-

ful in assessing the effects of pollution on marine resources and the affairs of man along the coast of southern California. The "monitoring" programs in the vicinity of certain sewage outfalls include frequent determinations of (1) the MPN of coliform bacteria in water and in bottom sediments, (2) dissolved oxygen, (3) transparency, (4) plankton population, (5) grease and oil, (6) salinity, (7) temperature, and (8) bottom fauna. Additionally, an extensive survey is being conducted to determine the numbers and kinds of marine organisms inhabiting coastal waters in areas as yet unaffected by discharged wastes. One research project is concerned specifically with the effects of such wastes on seaweeds.

REFERENCES

- American Public Health Association. 1955. Standard Methods for the Examination of Water, Sewage, and Industrial Wastes. A. P. H. A., Inc., New York, 522 pp.
- Brooks, N. H. 1952. Some ocean outfall studies. Los Angeles County Sanitation Districts, Sept., 55 pp.
- California State Bureau of Sanitary Engineering. 1943. Report on a pollution survey of Santa Monica Bay beaches in 1942. Calif. State Printing Office, Sacramento, 69 pp.
- California State Department of Public Works. 1952. Reclamation of water from sewage and industrial wastes. Calif. State Dept. Pub. Works Publ., Sacramento, 63 pp.
- Ewing, G. 1950. Slicks, surface films and internal waves. Jour. Mar. Res., 9: 161-187.
- Garber, W.F. 1956. Bacteriological standards for bathing waters. Sew. & Ind. Wastes, 28: 795-808.
- Greenberg, A. E. 1956. Survival of enteric organisms in sea water. Public Health Reports, 71: 77-86.
- Gunnerson, C. G. 1958. Sewage disposal in Santa Monica Bay, California. Jour. San. Eng. Div. Proc. Amer. Soc. Civil Eng., 84 (SA 1): Paper 1534, 28 pp.
- Harris, E.K. 1958. On the probability of survival of bacteria in sea water. Biometrics, 14: 195-206.
- Hartman, Olga. 1956. Contributions to a biological survey of Santa Monica Bay, California. Final report submitted to Hyperion Engineers, Inc. by the Geol. Dept., Univ. Southern Calif., Sept., 161 pp.
- Handerson, W. L. and Nelson, L. M. 1957. Bacterial studies related to disposal of sewage through ocean outfalls. Progress Rept. from Orange County Sanitation Districts, Santa Ana, Calif., 37 pp.
- Horrer, P.L. 1956. Sewage in Santa Monica Bay: A critical review of the oceanographic studies. Marine Advisors, P. O. Box 1001, La Jolla, Calif., 95 pp.
- Johannesson, J.K. and Martin, R. E. 1957. The determination of *Escherichia coli* I in sea water. Jour. Appl. Bact., 20: 151-157.
- Ketchum, B. H., Ayers, J. C., and Vaccaro, R. F. 1952. Processes contributing to the decrease of coliform bacteria in a tidal estuary. Ecology, 33: 247-258.
- McKee, J. E. 1952. Water quality criteria. Calif. State Water Pollution Control Board, Publ. 3, Sacramento, 512 pp.
- Moore, B. 1954. Sewage contamination of coastal bathing waters. Bull. Hygiene, 29: 689-704.
- Nusbaum, I. and Garver, R.M. 1955. Survival of coliform organisms in Pacific Ocean coastal waters. Sew. & Ind. Wastes, 27: 1383-1390.
- Nusbaum, I. and Miller, H.E. 1952. The oxygen resources of San Diego Bay. Sew. & Ind. Wastes, 24: 1512-1527.
- Orlob, G. T. 1956. Evaluating bacterial contamination in sea water samples. Public Health Reports, 71: 1246-1252.
- Orlob, G. T. 1956. Viability of sewage bacteria in sea water. Sew. & Ind. Wastes, 28: 1147-1167.
- Pearson, E. A. 1956. An investigation of the efficacy of submarine outfall disposal of sewage and sludge. Calif. State Water Pollution Control Board, Publ. 14, Sacramento, 154 pp.
- Rawn, A. M. and Bacon, V. W. 1957. Organization and accomplishments of the California water pollution control system. Sewage & Indus. Wastes, 29: 201-209.
- Rawn, A. M., Caldwell, D. H., and Hyde C. G. 1952. Report on the collection, treatment and disposal of the sewage of San Diego County. S. D. County Sewerage Survey, San Diego, Calif., 515 pp.
- Rittenberg, S. C. 1956. Studies on coliform bacteria discharged from the Hyperion outfall. Final report submitted to Hyperion Engineers, Inc., by the Geol. Dept., Univ. Southern Calif., Sept., 51 pp.

Rittenberg, S. C., Mittwer, T., and Ivler, D. 1958. Coliform bacteria in sediments around three marine sewage outfalls. *Limnol. & Oceanogr.*, 3: 101-108.

Rosenfeld, W. D., and ZoBell, C. E. 1947. Antibiotic production by marine microorganisms. *J. Bact.*, 54: 393-398.

San Diego Regional Water Pollution Control Board. 1952. Report upon the extent, effects and limitations of waste disposal into San Diego Bay. State of California, San Diego, Calif., 95 pp.

Stevenson, R. E., and Grady, J. R. 1956. Plankton and associated nutrients in the waters surrounding three sewer outfalls in Southern California. Univ. Southern Calif., Allan Hancock Foundation Report, 18 Sept., 48 pp.

Theroux, R. J. 1957. Enlarged sewage disposal facilities for Los Angeles. *Sew. & Indus. Wastes*, 29: 124-133.

Terry, R. D. 1956. An annotated bibliography on bacteriology, oceanography, and Marine Geology as they relate

to the disposal of waste material into the sea. Allan Hancock Foundation, Univ. Southern Calif., 112 pp.

Vaccaro, R. F., Briggs, M. O., Carey, C. L., and Ketchum, B. H. 1950. Viability of *Escherichia coli* in sea water. *Amer. Jour. Pub. Health*, 40: 1257-1266.

Warren, A. K. and Rawn, A. M. 1938. Disposal of sewage into the Pacific Ocean. Ch. 18 in *Modern Sewage Disposal*, Fed. Sew. Works Assoc., New York, pp. 202-208.

Weiss, C. M. 1951. Adsorption of *E. coli* on river and estuarine silts. *Sew. & Ind. Wastes*, 23: 227-237.

ZoBell, C. E. 1936. Bactericidal action of sea water. *Proc. Soc. Exper. Biol. & Med.*, 34: 113-116.

ZoBell, C. E. 1946. *Marine Microbiology*. Chronica Botanica Co., Waltham, Mass., 240 pp.

ZoBell, C. E. 1958. Occurrence and fate of coliform bacteria in the sea. *Proc. I Congreso Latinoamericano*, Mexico, D. F., pp. 58-68.

POLLUTION PROBLEMS ALONG THE GULF COAST

Gordon Gunter, Gulf Coast Research Laboratory - Ocean Springs, Mississippi

ABSTRACT

Pollution problems are very difficult because they involve many phases of science and engineering, and because they often concern organisms about which very little is known. For that reason, certain pollution problems have brought about considerable advances in several fields of science. One prime example is the great advance made in oyster biology following the filing by oystermen of a huge damage suit against the oil producers of the Louisiana coast. It was found that a parasitic fungus was the cause of the trouble and that oil and bleedwater were not the agents causing mortality. Another result was that the oil and sulphur companies became very sensitive to pollution problems and, in general, keep very clean along the Gulf.

There is one industrial center in Alabama and one in Mississippi on salt water, but these do not seem to cause any pollution troubles. There are a few scattered centers in Texas, but they have not been troublesome. The most

heavily industrialized area of the Gulf coast is in the Galveston Bay region. A thorough inventory of the vast industries and resulting effluents in that area has never been made. However, fish production and oyster production in Galveston Bay are apparently holding up. There are five paper mills in the West Florida region and one in Mississippi on the coast. These are Kraft mills and the Florida State Board of Health feels that only one causes any trouble. There are a few places in Florida, Texas and Mississippi where sewage pollution prevents the marketing of oysters. The difficulties of sewage pollution are slowly coming under control.

The industrial pollution problem on the Gulf coast is not very large now, but it will doubtless increase with time. The eastern two-thirds of the coast is fortunate in having an abundant supply of water, which makes control of pollution through dilution much easier than in many other parts of the country.

I discussed the matter of coming to Cincinnati with an old friend who has done a great deal for industry, which was assailed by charges of pollution. He told me he was not coming to this meeting because he did not like pollution problems. I cannot help but agree with him, in spite of the fact that I have been virtually dragged by the heels into pollution problems over the past twenty-five years. In fact, I should counsel any young biologist who intends to go into fisheries or wildlife research or oyster biology to try to learn something about pollution. This, of course, is rather discouraging advice because it means that one should learn all of the major principles and many of the details of general physiology, ecology, toxicology and a good deal about industrial chemistry, hydrology, and hydraulic engineering with the further understanding that they are becoming more complicated all the time. For instance, it appears that in the future a competent student in this field will also have to know a good bit about the physics and chemistry of isotopes and radioactive materials, as well as their effects upon

the physiology and the ecology of organisms, and possibly even effects upon the future potential development and evolution of the organisms with which he is concerned.

When we stop and consider that the life history of the vast majority of organisms is still imperfectly known, that ecology is a relatively new branch of biology and its intricacies are only as yet dimly perceived, that possibly its major principles are not even yet understood and that the physiologists themselves have not in the least run out of problems. Then add to this the idea that our use of water, soil and even the atmosphere is increasing by leaps and bounds, it is not hard to understand why many biologists view pollution problems with combined feelings of distrust and impotence. It is no wonder they prefer to turn to the relative simplicity of controlled conditions in the laboratory. Even there, I sometimes wonder if the biologist is not a little bit deluded. For instance, I have read dozens of papers and doubtless there are hundreds and thousands comparing an animal

held in simple tap water to other conditions. I have used the words "tap water" myself in writing papers and in looking back upon it I do not know precisely what I did mean, especially as compared to other tap waters.

I have noted the general tendency of all researchers to speak of the difficulties of their field and I am a bit wary of it because I suspect that it is a sort of inverted psychological trick of self-adulation. However, I must say that the pollution field is certainly the most complicated biological field that I have ever encountered and I have been in fairly close contact with a good many. With some of these things in mind I shall try to relate to you a few thoughts about pollution in the Gulf of Mexico.

Aside from its overwhelming importance, somber realities and dark side, there is no doubt that the pollution problem has had a very stimulating effect upon many fields of science. There is no better example than the vast conflict between the oil industry and the oyster industry on the Louisiana coast, which came to a head about 1949 when the oil industry was sued for approximately forty million dollars by the oystermen of the State of Louisiana. This was the largest civil suit ever filed in the United States up to that time, and even to the oil industry forty million dollars is not hay. A sulphur company was also sued. There was quite a reverberation and it resulted in what one man has called "The Manhattan Project of Oyster Biology." Studies were undertaken in hydrography, sedimentation, oyster ecology, physiology, and almost every related field one could think of. A number of important papers have resulted and they are still coming out. Almost every oyster biologist and would-be oyster biologist in this country, and some from Europe, was employed or retained in some manner. Not all of us were directed or would work with direction and my own contribution consisted of a re-examination of the generic status of the oysters of the world and a field study of the relations of oysters to salinity of environment. These had little to do with the primary problem and there were a number of other projects of greater importance to oyster biology. In this respect alone a great deal of progress was made. In addition, the oil industry cleaned up not only in spillage of oil, but in the disposal of bleedwater from the wells. Today, from the Rio Grande to as far as it goes to the east, the oil industry along the Gulf coast is clean. The upshot of this whole situation was that the trouble was found to be a parasitic

organism somewhat unsurely related to fungi. The oil industry in Louisiana has been cleared and the sulphur industry was similarly absolved. The oyster industry is still in trouble due to the summer efflorescence of the parasitic organism, which has affected it since about 1944. In high salinities oysters die in epidemic fashion during the summer. Other results of this investigation were the discovery of four or five other oyster diseases which have never been fully described and the stimulus upon some people to begin a study of the diseases of invertebrate aquatic organisms, a virtually untouched field of biology. These cases were settled on a nuisance basis at about 1 percent of the original demand. This meant that a number of the litigants received sums running as low as thirty or forty dollars while some shrewd lawyers, who had done practically nothing but file the suits, received the remainder. I would wish that all pollution problems could be settled with such small onus resting upon the would be polluters. I also suspect, however, that this case has led to a biased view. For instance, one of my colleagues, who is a very outstanding biologist, told me that when I came up here the only thing to say was that the only bay on the Gulf coast where there is industrial pollution is Galveston Bay and that it has the highest oyster production in the State of Texas. I told him that I could not string that out to a thirty minute talk. The view my colleague expressed is doubtless overly sanguine, but I am happy to say that the Gulf coast is probably freer from pollution than any other area of the United States coast at the present, and in that regard I shall give you a very brief review.

The coast of West Florida is an area of homes, tourist cabins, vacation resorts, etc. with a few orange groves. There are some intensely interesting and important problems there concerning the flow of fresh waters to the Gulf of Mexico and its possible relation to the Red Tide, but they are not concerned with pollution. There is also a great move on to dredge and fill some of these shallow bays to make low lying islands for real estate purposes. This has aroused considerable opposition by fishermen and conservationists but again they are not pollution problems and I personally cannot feel any great concern about them. I do not see that the creation of a few deeper areas down to 18 feet can make any difference in this shallow coast where many flats are exposed or almost exposed at low tide.

An official of the State of Florida gave me his summary of conditions in Florida in the following terms which I have somewhat abstracted.

1) Certain cities along the Gulf have allowed themselves to become industrialized or deliberately planned it that way. These are Pensacola, Panama City, Port Saint Joe and Fernandino. Other towns have resisted the payroll attraction and have tried to keep industries out. Many towns which have tried to merit industry have failed. These retain pure waters against their will.

2) One of the most hopeless tasks I can imagine is to try to mitigate or eliminate pollution. The industrial corporations are politically powerful and furnish large payrolls. Public opinion is for keeping these sources of revenue. In at least two cases impoverished counties have passed local laws naming certain coastal rivers "industrial streams." By such action unlimited pollution is granted with complete impunity.

3) Sewage pollution is slowly improving, but many highly productive oyster beds are still immobilized by the State Board of Health. There is far greater hope for the future control of sewage pollution than for industrial pollution.

This informant states that the Florida State of Health has authority over pollution and finds it very difficult with which to deal.

I might add parenthetically that sewage pollution is purely a health problem, and so far as I know no biologist has ever maintained that raw sewage pollution hurts or injures the bay environment. In fact, it only fertilizes the water.

The chief industrial concerns along the north Florida coast are paper mills. The information I have gained from the Florida State Board of Health is much more hopeful than the above remarks. The eastern-most mill is located in south Georgia just north of the Florida state line. The effluent is treated in a series of lagoons and eventually finds its way into the Suwannee River. The treatment is about 90 percent effective and the Board of Health thinks the mill has done a good job. I personally know of no ill effects in the lower Suwannee River and the adjacent Gulf. There is a mill which discharges its waste into the Fenholloway River. This treatment is not considered to be effective. At Port Saint Joe a paper mill releases its waste

just offshore into the tidal waters. At Panama City there is a mill which lagoons its waste and then releases it into the Sound offshore. Just north of the Florida-Alabama line there is another mill which releases its waste into the Escambia River, after passing it through sedimentation basins, and another one at Pensacola does the same thing before releasing waste into Perdido Bay. The State Board of Health feels that the last three mills have done a fairly good job of handling their wastes by making plant changes and by treatment of the effluent. It is believed the situation has improved the last few years even though production has increased considerably. In summary, of the five paper mills on the Florida coast only one seems to be causing serious concern. It is my understanding that these are all Kraft mills. There is no other important pollution in the area.

In Alabama there are no paper mills on the coast. There is some industrialization around the city of Mobile at the very head of Mobile Bay, but it is mostly with shipping and shipyards and the like and apparently has caused little trouble. Alabama has had some serious problems in connection with insecticides and cotton dusting, but these have not influenced the coast. In general we might say that Mobile Bay and that part of Mississippi Sound within the State of Alabama is unindustrialized and clean.

In Mississippi we have one industrial center, the town of Pascagoula. This is a large ship-building center and one atomic submarine has already been built there. Two more are under construction. As you know, these activities are rather rigidly supervised and as yet there is no indication of trouble. There is also a large Kraft mill just north of this area, which perfumes the atmosphere for a good many miles around, but otherwise it seems to cause no trouble. There are several menhaden plants and cat-food factories in the area but their wastes are almost purely organic. They have considerable oxygen demand, but they cause no permanent damage and in the long run fertilize the water. One chemical company in the area, which manufactures ammonium nitrate and certain acids, caused some trouble due to plant malfunction but this has been rectified. A sugar factory is moving into the area and I was told that their effluent would have a BOD of three million pounds a day. I was a little disturbed at this and told the people there was not that much oxygen in the county. What will happen when that thing

gets into operation remains to be seen. Fortunately, there is no oyster production in the area and not much fishing immediately close by. Possibly this material can be released into the Sound where it will only affect a localized area and tend to fertilize the Sound.

In the Bay of Biloxi there is a sewage problem and the State Health Department does not permit the harvesting of oysters from that area. Along the remainder of the Mississippi coast there is nothing but dwellings and vacation centers and no pollution problems.

The Louisiana coast is marsh from one end to the other and there is no industry, except oil and sulphur production. The majority of industrial plants of Louisiana lie along the Mississippi River, mostly between New Orleans and Baton Rouge. The dilution factor takes care of all problems and the city of New Orleans uses the Mississippi River water after settling and bacterial purification.

The situation in the marshes deserves some special comment. As I said before, the oil companies have cleaned up. In many instances the bleedwater is pumped back into the ground and the companies have found out that this helps maintain the pressure of the fields and thus they get a better oil yield in the long run. In the few cases where this is not done, the dilution factor takes care of the problem because the salt components of these brines are not greatly different in ratio from those in sea water. Some careful experiments have shown that it takes a solution of 10 percent bleedwater to affect the pumping rate of oysters. The companies are sensitive to oil loss because oysters will quickly take up the taste of oil and thus become unfit for market. Even the small amounts of oil which are mixed with drilling muds cause trouble and the companies are sometimes brought up against a claim for damages, which they usually settle out of court.

The Freeport Sulphur Company is equally sensitive and does everything in its power to prevent pollution. Sulphur itself seems to cause no trouble and oysters set and grow quite well on blocks of solid sulphur. The main problem is with the bleedwater and this is diluted before it is released. I might state here that the eastern Gulf coast, and Louisiana especially, has ample supplies of water with which to alleviate pollution problems. The Freeport Sulphur

Company has constructed a large offshore platform and has gone to considerable lengths to see that the bleedwater causes no trouble. Our own Laboratory is carrying on a faunistic survey of the whole surrounding area on a semi-quantitative basis using plankton tows, bottom grabs, dredges and fouling collectors, and we shall have a year's cycle of these data before the mine is in operation. Mr. C. E. Dawson, who is attending this meeting, is carrying on this work from a laboratory on Grand Isle, Louisiana. This program follows along lines of non-official advice from various members of the Louisiana Wild Life and Fisheries Commission.

The Beaumont-Port Arthur area of the east Texas coast is considerably industrialized, mostly by the oil industry. These refineries largely use water for cooling and do not let out toxic effluents. They have also been affected by the general clean up of the oil industry and there seem to be few problems in that area.

To the far south on the Texas coast there is a plant at Bishop, below Corpus Christi, where synthetic fibers are manufactured. They have some very toxic effluents which are lagooned in what virtually amounts to a lake. These materials oxidize and go away without any particular pollution to the atmosphere, but I am told that occasionally a poor duck is attracted to this watery-looking body and is never able to leave it once he lights. This region is extremely dry but occasionally there is a cloud burst and once the dikes on this lake broke, letting the material flow into Baffin Bay where it killed large numbers of fishes. However, these matters have been rectified.

A little farther to the north the city of Corpus Christi has alkali and other chemical plants, but this region does not have much water and apparently will not grow in the future until a supply can be obtained. There has been no evidence of injurious pollution in Corpus Christi Bay. It is a well known fishing area and has remained so. One hundred miles farther north on Matagorda Bay the Aluminum Corporation of America has built one of its largest plants, across the bay from the small town of Port Lavaca. I do not think that this plant puts anything into the water except a little bauxite dust, which after all is just another kind of earth. In any case, there is no report of trouble.

At the city of Freeport the Dow Chemical

Company plant operates. Among other things it manufactures magnesium and bromine from sea water. Its effluent consists largely of changed sea water with no toxic qualities.

I have left the Galveston Bay area to the last because actually it is the only heavily industrialized area on the coast of the Gulf of Mexico. Large oil refineries exist in Baytown. There are large chemical plants, rubber plants, a tin plant, and others at Texas City, which you may remember was the scene of what was possibly the largest non-atomic explosion in the United States. The city of Houston lies at the northern end of the bay and there industrial concerns and their types are legion. I cannot enumerate them and I am not acquainted with the types of pollution or the volumes of effluents. In fact, the Texas Game and Fish Commission has been trying to make an inventory of these effluents for some time and I think they are still at it. I

do not know what influence this area has on the bay. The Texas oyster industry is not of great size, but some of the best reefs in the State are in the southern part of Galveston Bay. There has never been any indication that they were damaged by industrial pollution. The Houston urban area is the fastest growing one in the United States. This may account for the fact that thirty-eight percent of the sports fishing in Texas is done in the Galveston Bay area. The state total sports catch of four common fishes, redfish, speckled trout, drum and flounder, last year was thirty-five million pounds. Of this amount 36.5 percent came from the Galveston Bay area. Thirty-eight percent of the fishing and 36.5 percent of the fish does not indicate any great decline in the fish population in the Galveston area, compared to the remainder of the Texas coast, most of which is totally lacking in either industrial or sewage pollution.

ECOLOGICAL EFFECTS OF SEWAGE POLLUTION IN BISCAYNE BAY, FLORIDA: DISTRIBUTION OF COLIFORM BACTERIA, CHEMICAL NUTRIENTS, AND VOLUMES OF ZOOPLANKTON^{1, 2}

J. Kneeland McNulty, Ernest S. Reynolds and Sigmund M. Miller
The Marine Laboratory, University of Miami

ABSTRACT

Ketchum's Intertidal Volume Concept is applied to the distribution of coliform bacteria in Biscayne Bay, Florida. Due to irregularities of shoreline and bathymetry, segment boundaries follow section contours based on the observed mean excursion of a particle of water in the flood tide. The resulting segmentation pattern is interpreted to mean that river water in the main ship channel is flushed from the bay

in roughly 7 to 9 days and in other parts of the bay where flushing occurs at all in roughly 8 to 11 days. Application of the theory to coliform bacterial distribution accounts for an average MPN decrease of almost 98%. The final predicted MPN is about 4 times higher than the observed value. Data on chemical nutrients, plankton volumes and water color are presented and discussed.

INTRODUCTION

Full activation of the Miami Sewage Disposal Plant in December, 1956, resulted in diversion of some 30 to 50 million gallons per day of raw sewage from the Miami shoreline of Biscayne Bay to the plant. Several years before construction of the plant it was realized by Dr. F. G. Walton Smith, director of the Marine Laboratory, that this action would have broad effects on the ecology of the bay and that an unusually good opportunity presented itself for direct observations of the processes taking place. By late 1953, ecological observations were begun which would permit comparison of ecological conditions before and after plant activation.

Observations made before plant activation can be grouped in 5 broad categories: hydrographic, bacteriological, chemical, sedimentary, and biological. The hydrographic results have been published (Hela, Carpenter and McNulty, 1957). The bacteriological, chemical and zooplankton results form the body of this paper. The sedimentary and additional biological results await future publication.

Surveys of sewage pollution in estuaries show the rapid decrease of coliform bacteria seaward

from sewage sources. The rate of decrease is greater than that which would be expected from dilution alone. Greenberg (1956) has published a review of the various known factors which contribute to the decrease. These factors include production by aquatic organisms of unidentified antibiotic substances, adsorption and sedimentation, predation, and competition for the limited food supply. Heretofore, only one attempt has been made to evaluate quantitatively the processes contributing to the decrease of coliform bacteria in a tidal estuary (Ketchum, Ayers and Vaccaro, 1952). These authors evaluate mathematically the relative effects of dilution, the bactericidal action of sea water, and predation. They conclude that these three processes account for more than 99% of the decrease of coliform bacteria in the Raritan River, and that bactericidal action is the most important process. Formulations of the dilution and bactericidal processes are combined, and in a later paper (Ketchum, 1955) the combined formulation is used to explain the distribution of pollution in estuaries.

This paper attempts to apply Ketchum's method to Biscayne Bay. Observed coliform densities are compared with predicted densities.

¹ Contribution No. 243 from the Marine Laboratory, University of Miami

² This investigation was supported by grants E-510 and RG-4062 from the National Institutes of Health, Public Health Service.

Marine Laboratory data (Reynolds, 1955) and results of a Florida State Board of Health pollution survey (Minkin, 1949) are the observed densities. Predicted densities are those which have been derived from Ketchum's equations. In addition, data on the distribution of chemical nutrients, plankton volumes, and water color are presented and discussed.

The field work was planned jointly and carried out by the senior author, assisted at times by Mr. Clarence A. Carpenter, Jr., and by various graduate students. Combined bacteriological, chemical and plankton sampling was done at 15 stations (Figure 1). Analysis of the data has been done by the senior author. Dr. Ernest S. Reynolds supervised bacteriological sampling, performed MPN determinations and reduced the data to usable form (Reynolds, 1955). All chemical sampling and laboratory determinations of phosphorus and nitrogen components were under the supervision of Mr. Sigmund M. Miller. Over-all supervision was exercised by

Dr. F. G. Walton Smith assisted by Drs. Charles E. Lane and Hilary B. Moore. Mr. James H. Hartwell, Engineer-in-Charge, Surface Water Branch, U. S. Geological Survey, Miami, Florida, and Dr. Fritz Koczy of the Marine Laboratory were consulted on matters pertaining to the analysis.

Biscayne Bay is classified as a positive, shallow, tidal bar-built estuary. The geomorphology, bathymetry and hydrography of formerly polluted parts of the bay are described in detail by Hela, et al. (1957). Smith, Williams and Davis (1950) published the only previous data on chemical nutrients and plankton of the study area. Pertinent qualitative plankton data appear in Davis (1950) and in Woodmansee (1949). There has been no significant industrial pollution in the Miami area.

METHODS

Water samples for bacteriological and chemical tests were collected at the same time and in the same way. Field work was planned in advance so as to sample at as many different stages of the tidal cycle as possible. A clean bucket rinsed with the water to be sampled was used to fill a chemically sterilized, thoroughly rinsed 5-gallon carboy with water taken a few inches below the surface. The MPN samples were siphoned immediately through clean and rinsed surgical tubing to sterile bottles. These were immersed completely in an ice-and-water mixture for 15 minutes to chill them to approximate storage temperature, then stored at about 5°C in a cold air box for two to three hours before laboratory treatment. Coliform presumptive tests were made on all samples using Lactose Broth in five replicates at five dilutions with readings of three significant tubes after 24 hours (American Public Health Association, 1946). Occasional additional readings were made after 48 hours. Confirmatory Brilliant Green Lactose Bile Broth tests were made for various representative stations and whenever confirmation was desired in doubtful cases.

Samples for chemical analyses were taken from the 5-gallon carboy, filled as described above. Nitrate-nitrogen and nitrite-nitrogen tests were made on chloroform-preserved samples. The method of Bendschneider and Robinson (1952) was used for determination of nitrite-nitrogen. One ml. of 1% sulfanilamide in 1.2 N HCl and one ml. of 0.1% N-(1-naph-

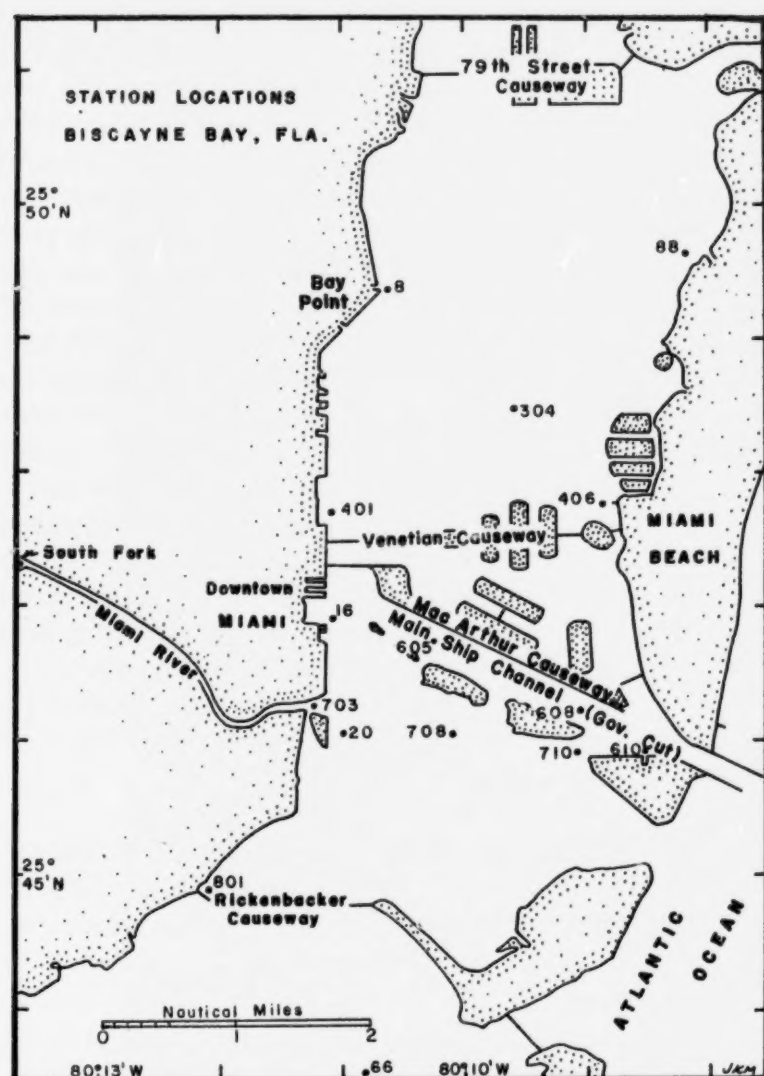


Figure 1. Station locations, Biscayne Bay.

thyl) ethylenediamine dihydrochloride were added to a 50 ml. sample and the optical density compared with that of standards in a Beckman spectrophotometer, using 10 cm. absorption cells.

The method of Fyn (1951) was used to prepare samples for analysis of nitrate-nitrogen. A 100 ml. sample was reduced over 40 g. of 10 mesh zinc in 1:20 HCl by heating in a boiling water bath for 1-1/2 minutes. The sample was then analyzed in the same manner as for the nitrite-nitrogen, except that the standards were prepared from sodium nitrate solutions which were reduced in the same manner as the samples.

Phosphate-phosphorus determinations were made on board using the method of Robinson and Thompson (1948). Thirty-centimeter Nessler tubes were used for visual comparison of the samples with standards. Since the water samples were frequently contaminated with sewage, tannins, etc., it was found advantageous to modify the method of visual comparison. In addition to preparing a set of standards for each group of determinations, a Nessler tube was filled to the brim with stock sodium chloride solution used for preparation of the standards, and a second tube was filled to the brim with water from the station being sampled. These two tubes were placed directly under the standard and water sample tubes, respectively, during visual comparison. By doing this it was possible to compensate for the interference caused by discolored bay water.

As soon after collection as possible, a measured volume of sample from the carboy was passed through a Sharples Super Centrifuge. A volume of 5-7 liters was found to be convenient for this purpose. The method of Hansen and Robinson (1952) was employed to determine total dissolved phosphorus in the filtrate. From this and the phosphate-phosphorus analysis, the dissolved organic phosphorus was determined by difference. Particulate matter retained by the centrifuge was washed into a 125 ml. Erlenmeyer flask and oxidized by heating with 5 ml. portions of nitric acid until the sample became colorless. The perchloric acid method of Hansen and Robinson (1952) was then used to determine the particulate organic phosphorus concentration.

Plankton samples were obtained with the Clarke-Bumpus sampler and No. 2 net at a depth

of about 2.5 ft. Calibration was done in the field over a measured mile at the normal speed of towing (about 4 kts.) and gave the value of 4.76 liters per cycle (compare Clarke and Bumpus, 1940). Volumetric analyses were done by draining a plankton sample on a piece of No. 2 net, then determining sample displacement volume in a small graduate cylinder.

Water color was noted by visual observation in the field each time samples were taken. A total of 123 such observations were recorded at all tidal stages.

TIDAL FLUSHING

Coliform populations in an estuary are distributed by water movements and they are diluted by sea water. The rate of circulation determines the time they are exposed to mortality from various causes. The exchanges of fresh and salt water determine dilution. Both factors have been calculated by Ketchum's Intertidal Volume Concept (Ketchum, 1951).

Bacteriological application of the theory requires subdivision of the estuary into volume segments defined horizontally by the width of the estuary and by the mean excursion of a particle of water in the flood tide (Ketchum, *et al.*, 1952). The theory was applied originally to the Raritan River, a long and narrow estuary. The theory has not been applied heretofore to an estuary such as Biscayne Bay, characterized by extreme non-uniformity of width, extensive areas lateral to polluted portions which have little influence on circulation of the pollutant, and tidal currents directed mainly through numerous dredged channels. Therefore, in applying Ketchum's method, segment boundaries have followed section contours based on the observed mean excursion of a particle of water in the flood tide.

Previously reported flood tide current data were used (Hela, *et al.*, 1957). Average flood tide current velocities were computed on the assumption that the tidal curve approximates a cosine curve and that the average current velocity is 2π multiplied by the maximum flood tide velocity, as done by Ketchum (1950) in checking his results on the Raritan River and Bay. Section boundaries, followed later when drawing segment boundaries, were determined by the distance of average flood tide transport in a single tide measured from the Miami River

mouth outward into the bay (Figure 2, Arabic numerals). A chart of streamlines of velocity for the flood tide surface currents was used (Figure 3). In the figure, the length of the solid arrows is proportional to average flood tide velocity. The dotted lines are interpolations between measured currents. Surface areas from planimeter readings multiplied by depths of mean low water (U.S. C. & G. S. Chart No. 848) gave the low tide volumes of individual sections. Meantidal range of 2.0 ft. (U.S. D. C., Tide Tables, 1954) was used for calculation of mean tidal prism volumes.

Table 1 shows cumulative volumes of the sections. Inner end of the estuary was placed across the Miami River at its junction with South Fork (approximately three nautical miles inland from the mouth). Choice of this location was based on weekly chloride data for the period of this study obtained by the U.S. Geological Survey. The data clearly show that at a point

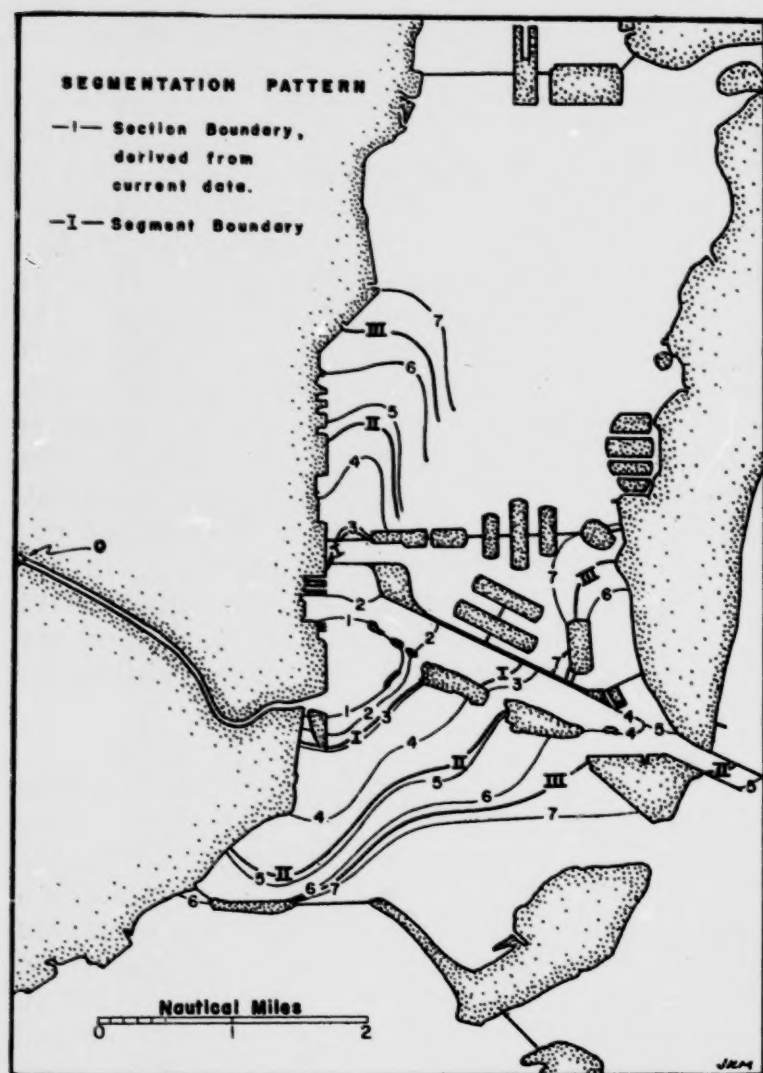


Figure 2. Streamlines of velocity, average flood tide surface currents.

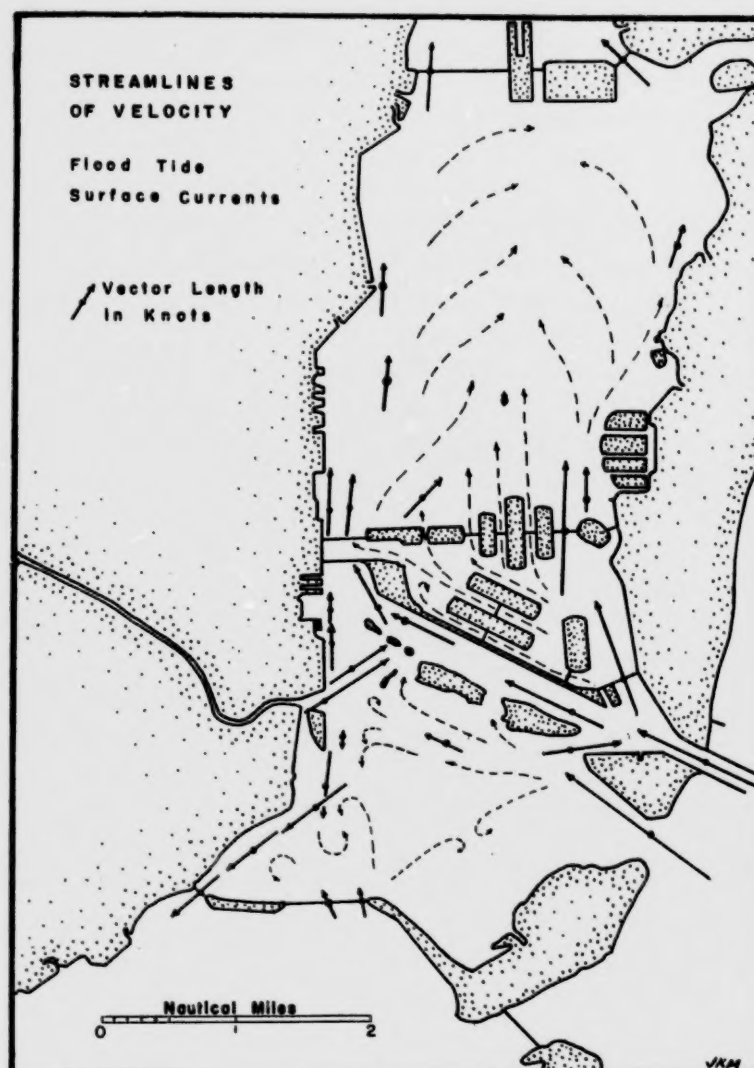


Figure 3. Segmentation pattern, showing section boundaries (Arabic numerals) from which segment boundaries (Roman numerals) were in part deduced.

in the Miami River between N.W. 17 and 27th Aves., salinities reached essentially zero, thus fulfilling the requirement of Ketchum's theory that the water landward from the inner end of the estuary is fresh at all times. Mean river discharge at the mouth was estimated by Hela, et al., (1957) as $36 \times 10^6 \text{ ft.}^3$ during one tidal cycle. Because the discharge at S. Fork probably is less by about 5%, the mean discharge per tidal cycle of $35 \times 10^6 \text{ ft.}^3$ was used. Calculation of the intertidal volume of the Miami River and tributaries inland from S. Fork totalled only $28 \times 10^6 \text{ ft.}^3$. This figure was not used because probably the net effect of highly porous canal banks in the Miami area is to decrease the intertidal volumes. It is suggested that since water table level is roughly at mid-tide level in the canals, ground water flows into the canals at low tide and out of the canals at

Table 1. Miami River - Biscayne Bay Cumulative Volume Sections

Mean flood tide excursion boundary (See Figure 2)	Low tide (x 10 ⁶ ft. 3) V	Tidal prism (x 10 ⁶ ft. 3) P	High tide (x 10 ⁶ ft. 3) V + P
Miami Canal & Tributaries to S. Fork of Miami River (0)	270	35	305
S. Fork to mouth of Miami River	300	42	342
1	365	66	431
2	452	93	545
3	597	130	727
4	772	195	967
5	1,016	279	1,295
6	1,334	384	1,718
7	1,654	484	2,138

high tide producing a net decrease below true intertidal volume which can not be evaluated quantitatively at this time. The Dade County Engineering Department supplied maps and aerial photographs from which the low tide volume of fresh water inland from S. Fork was calculated. Data on the penetration of tidal influence inland were supplied by the U. S. Geological Survey. Inland from Miami fresh water is contained in a network of inter-connecting drainage canals and borrow pits. Tidal influence was felt as far inland as Pensuco, some 19.4 miles from the mouth of the Miami River, and along the Tamiami Canal to some 12.5 miles inland from its junction with the Miami River. Three large borrow pits about 20 ft. deep connect with the fresh water drainage canal system. Tidal fluctuations are felt in all three. After consulting with the U. S. Geological Survey it was decided that their effective depth insofar as they contribute fresh water to the bay is approximately the depth of their sills to connecting canals, or about 8 ft. Salt dams were not installed at the time of this survey.

Bay volumes were calculated only for those parts of the bay where flushing is most intense. This eliminated most of the area between Venetian and 79th Street Causeways. Hela, *et al.*, (1957 - Figure 10) show by the horizontal distribution of the absolute salinity range the areas with different intensities of flushing. In addition, a correction for incomplete vertical mixing was applied, as done previously in studies by Austin (1954), Ketchum (1951), and Tully (1949). Morrill and Olson (1955) state, "Because of the over-all shallowness of Biscayne Bay, a two layer estuarine system exists mainly in the several channels which average 30 ft. deep and

through which major tidal currents course. The two layer character is apparent in Government Cut in which the surface water salinity is less than the bottom water salinity. During the latter part of the flood tide there is no difference between surface and bottom water salinities (Hela, *et al.*, 1955)." Unfortunately, in the work referred to by Morrill and Olson, no vertical salinity samples were taken in the landward portion of the main ship channel westerly from Sta. 608 (see Figure 1 above). This landward portion, comprising some 70% of the main ship channel, was sampled vertically by Theroux (1928) whose data show evidence of a two layer system at all tidal stages. Theroux's data also show that stratification becomes increasingly pronounced toward the Miami River. Therefore, it was decided to consider vertical mixing as complete to about half depth (15 ft.) in deep areas of the bay, and complete to full depth in areas less than 15 ft. deep.

Figure 4 shows the volume relationships from which segment boundaries were determined. Segment volumes are shown in Table 2.

The theory produced a flushing time of about 8.5 to 10.5 days depending on the path followed by the water (Table 3). The segmentation pattern is interpreted to mean that fresh water (flowing into the main ship channel is flushed from the bay more rapidly than fresh water outside this channel. By this interpretation the main ship channel is flushed in about 8.5 days and other parts of the bay in 10.5 or more days. Most of the area between Venetian and 79th St. Causeways is subject to pumping action only by the oscillating tidal currents as distinguished from flushing action in the main ship channel and adjacent areas.

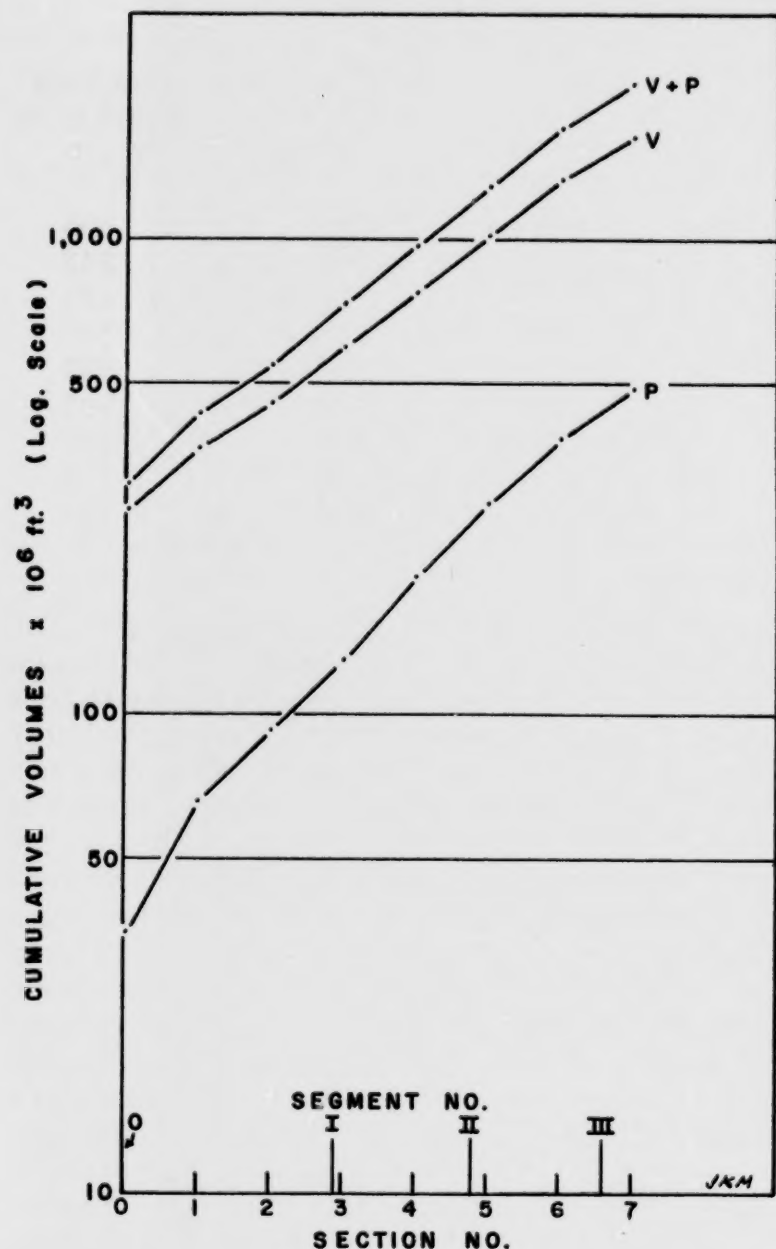


Figure 4. Cumulative intertidal (P), low tide (V) and high tide (V + P) water volumes.

The observed accumulations of fresh water (Tables 4 and 5) were calculated from salinities reported by Hela, *et al.*, (1957 - Figures 7, 8 and 9). A weighted average method was used by which

$$\bar{s}_n = \frac{\sum (VS)}{\sum V}$$

in which $\bar{s}_n$ is the average salinity in n section of segment, V is the volume of a portion of the section or segment having a salinity of s . Four overlays on the chart (U. S. C. & G. S. 848) were used: one each of the isohalines for low, mean and high tides, and one showing the section and segment boundaries. After making planimeter and depth readings (the latter corrected for the three different tidal stages), volume calculations were obtained for the various salinity increments. Salinity increments were chosen at the smallest practicable intervals, generally 1 ‰ apart where possible. A base salinity of 36 ‰ was used for the calculation of traction of fresh water in the various segments (Table 5). The comparison of observed and calculated accumulations of fresh water is shown in Figure 5. This figure shows a final deviation in cumulative fresh water volume of about 16 percent, with the calculated accumulation high as compared with the observed accumulation. One possible reason for this is that the observed accumulation is based on maximum salinities which "correspond, at least in a few cases but certainly not always, to the slack after flood" (Hela, *et al.*, 1957 - p. 62). Since maximum salinities were used, it is probable that somewhat lower salinities were attained generally at slack after flood.

Table 2. Segmentation of Miami River and Biscayne Bay Using a River Flow of $35 \times 10^6 \text{ ft.}^3$ (806 cfs) per Tidal Cycle

Segment No.	Distance from Miami River mouth	Cumulative volumes		
		Low tide $\sum_0^n V$	Tidal prism $\sum_0^n P$	High tide $\sum_0^n (P+V)$
0	(See Fig. 2)	270	35	305
I	"	575	125	700
II	"	970	262	1,232
III	"	1,502	440	1,942

Table 3. Calculated accumulation of river water in Miami River and Biscayne Bay using a river flow of 35×10^6 ft.³ (806 cfs) per tidal cycle.

Segment No.	Local Volumes		Exchange ratio r	Accumulation ($\times 10^6$ ft. ³)	
	Intertidal ($\times 10^6$ ft. ³) P_n	High tide ($\times 10^6$ ft. ³) $P_n + V_n$		Q_n	$\Sigma^n Q$
0	35	305	0.115	304	304
I	90	395	0.228	154	458
II	137	532	0.258	136	594
III	178	710	0.251	140	734

$734/35 = 21$ tidal cycles = approximately 10.5 days

$594/35 = 17$ tidal cycles = approximately 8.5 days

Table 4. Miami River - Biscayne Bay observed accumulation of fresh water

Section No.	Low tide ($\times 10^6$ ft. ³)	Mean tide ($\times 10^6$ ft. ³)	High tide ($\times 10^6$ ft. ³)
0	270	288	305
1	343	352	365
2	387	389	396
3	452	442	438
4	528	505	497
5	612	568	554
6	714	643	615
7	817	720	678

Table 5. Observed high tide accumulation of fresh water

Segment No.	High tide volume ($\times 10^6$ ft. ³)	Fraction fresh	Volume fresh ($\times 10^6$ ft. ³)	Cumulative volume fresh ($\times 10^6$ ft. ³)
0	305	1.000	305	305
I	395	0.238	94	399
II	532	0.205	109	508
III	710	0.155	110	618

$618/35 = 17.7$ tidal cycles = approximately 8.9 days

$508/35 = 14.5$ tidal cycles = approximately 7.3 days

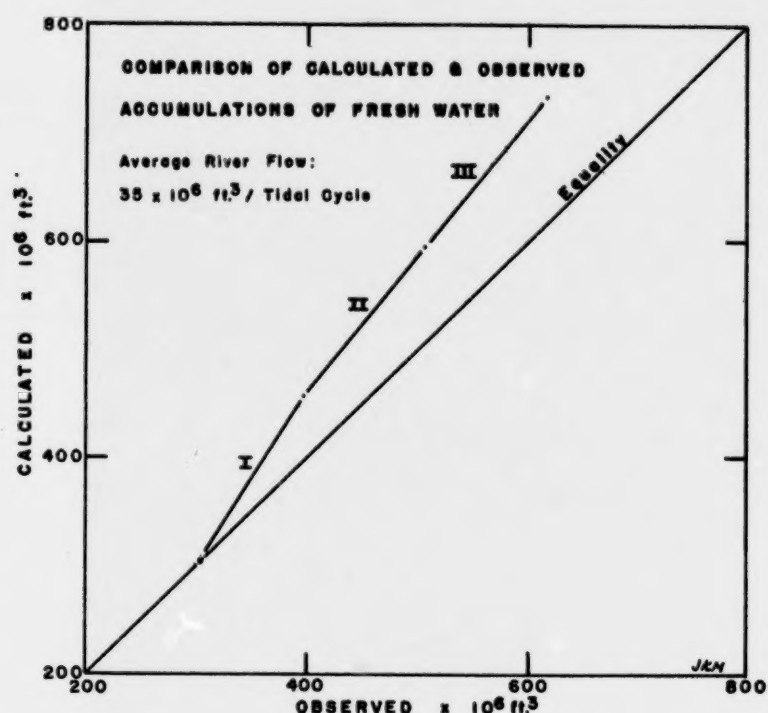


Figure 5. Comparison of calculated and observed accumulations of fresh water.

The observed accumulation of fresh water produced a flushing time of about 7.3 to 8.9 days. By the same interpretation used above with respect to theoretical flushing times, the observed flushing times are about 7.3 days for the main ship channel and about 8.9 days for areas near the main ship channel where flushing occurs at all. The theoretical and observed flushing times can be combined in order to draw a conclusion based on both sets of data, as follows: since river discharge and tidal amplitude vary almost daily, flushing times are best described by a range of values which the above data indicate are roughly 7 to 9 days for the main ship channel and roughly 8 to 11 days for other parts of the bay where flushing occurs at all.

APPLICATION TO COLIFORM DISTRIBUTION

Ketchum's (1955) formula for the distribution of coliforms is:

$$C_n = (C_0)_n \frac{r_n}{1 - (1 - r_n)e^k}$$

in which C is the average concentration of coliforms, n is a tidal excursion segment, r_n is the exchange ratio of that segment, e is the base of the natural logarithms, and k is the coefficient of mortality. The increment to the population

considered, $(C_0)_n$, from the adjacent segment $(n - 1)$ in the direction of the source of pollution, is given by:

$$(C_0)_n = C_{n-1} \frac{f_n}{f_{n-1}}$$

in which f is the fraction of fresh water.

The same coefficient of death rate (1.15 days^{-1} or 0.578 tides^{-1}) used by Ketchum, *et al.*, (1952) was used. A predation factor has not been applied in this study, for two main reasons: 1) there is no satisfactory evidence that the macro-zooplankton feed on coliform bacteria, or if they do, at what rate and with what effect on coliform populations; 2) existing data show that the numbers of macro-zooplankters in Biscayne Bay are less than the numbers per liter in Raritan River to the extent that if the same filtering factor were applied (10 ml. per tidal cycle), the result would be a negligible reduction in coliform counts. Zooplankton volumes and numbers per liter are discussed in a later section of this paper.

Results of direct application of the above formula to the Biscayne Bay coliform data are shown in Tables 6 and 7. The populations at low tide are taken as equal to the population expected in the adjacent landward segment at high tide decreased by mortality due to bactericidal action which occurs during a half tidal cycle, as similarly done by Ketchum, *et al.*, (1952). High and low tide results have been averaged and compared with previously reported Marine Laboratory data (Reynolds, 1955). Figure 6 is a semi-logarithmic plot of the predicted and observed MPNs. An additional set of MPN data obtained by the Florida State Board of Health (Minkin, 1949) are available. Although the predicted values are based on conditions at the time of the Marine Laboratory survey, it is clear that the Board of Health data follow the same trend.

These results suggest that a reasonably good prediction of coliform bacterial distribution in an estuary such as Biscayne Bay can be obtained by combining the results of an hydrographic survey with Ketchum's intertidal volume concept. If the primary objective of such a survey is prediction of pollutional distribution using Ketchum's method, hydrographic field procedures can be greatly simplified. Obviously, once the flushing parameters are determined, application of Ketchum's method to both con-

Table 6. Numbers of coliform bacteria predicted for various segments of Biscayne Bay, using a base concentration in Miami River of 352,000 coliforms per 100 ml (MPN)

Tide Condition	Segment No.	Average fraction fresh	Predicted average MPN	
			Dilution alone ($\times 10^3$)	Dilution and mortality ($\times 10^3$)
High	I	0.238	84	34
	II	0.205	29	14
	III	0.155	11	4.7
Low	I	0.577	203	152 [#]
	II	0.377	133	25
	III	0.340	120	11

Table 7. Comparison of predicted average coliform counts and observed average coliform counts

Segment No.	Predicted average MPN ($\times 10^3$)	Observed average MPN	
		Station	MPN ($\times 10^3$)
0	352	703	290
		16	59
		605	57
		20	42
I	93	401*	37*
		608	27
		610	8.4
		708	3.6
II	20	8*	9.8*
		801*	9.0*
		710	2.5
		406	1.1
III	7.9		

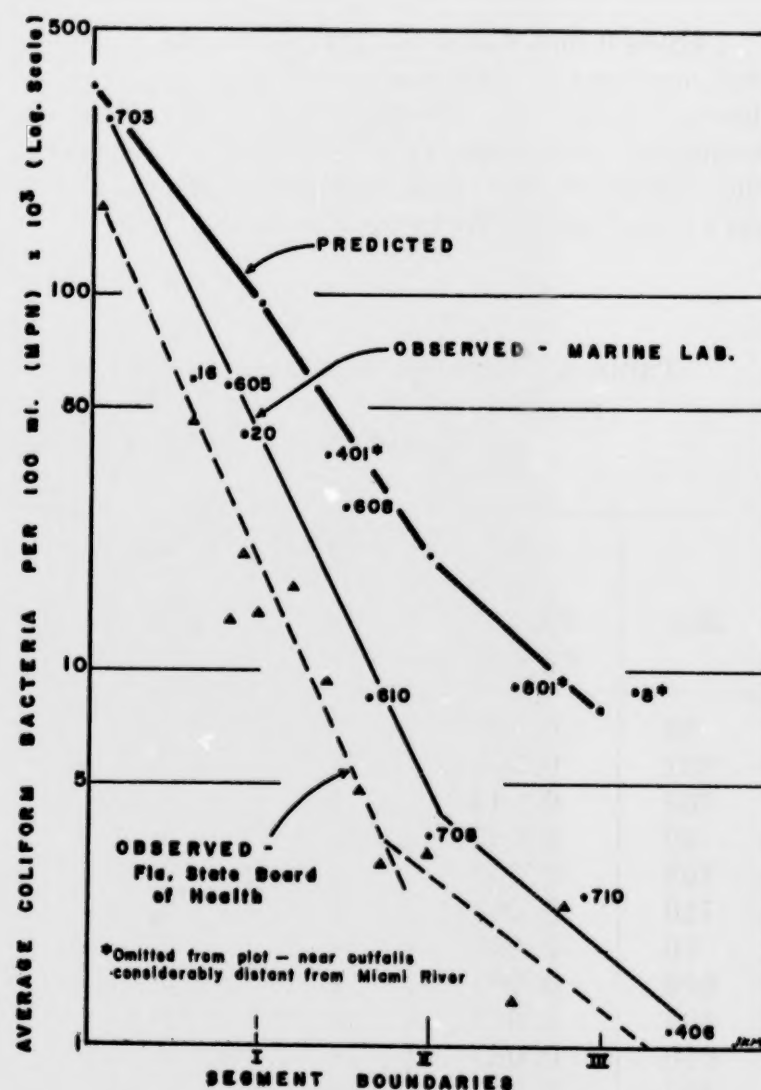


Figure 6. Comparison of predicted and observed quantities of coliform bacteria.

[#] From mortality in 1/2 tidal cycle after dilution.

* These stations located close to shore where fresh sewage from nearby outfalls increased coliform counts above counts which would have been recorded from sources in the Miami River and vicinity alone.

servative and non-conservative pollutants is accomplished readily provided that the decay rates of the latter are known.

CHEMICAL NUTRIENTS, PLANKTON VOLUMES AND WATER COLOR

Chemical nutrients have been studied in order to learn the extent to which sewage added nutrients to the bay. This paper reports only measurements made before activation of the Miami Sewage Disposal Plant. Comparison of future measurements to these data may provide information on nutrients supplied by sewage alone, since other ecological factors will have remained essentially the same.

Tables 8 and 9 summarize the chemical data. The horizontal distribution of phosphate-phosphorus, based on average concentrations throughout the tidal cycle, is shown in Figure 7. The figure shows that highest concentrations were found generally in the most heavily polluted

parts of the bay. Smith, et al., (1950) reported almost complete absence of phosphate at stations several miles south of Miami in Biscayne Bay. They found that this result was consistent with past studies of surface tropical waters generally and south Florida in particular.

The plankton volume data appear in Table 10. Due to the net used (No. 2), only the larger zooplankton were caught. The horizontal distribution of plankton volumes shows maximum values generally in the north bay area (Figure 8). As mentioned above the north bay area received abundant chemical nutrients and was subject to little or no tidal flushing.

Ketchum, et al., (1952), have estimated that up to 55 percent of the coliform bacteria surviving dilution and bactericidal effects were removed by predation by the larger zooplankters. Since the sampler and net types were the same in both the Raritan River and Biscayne Bay studies, it is pertinent to compare the two sets of data. Counts have been done on seven

Table 8. Mean particulate-phosphorus (1), phosphate-phosphorus (2), dissolved organic phosphorus (3), and total dissolved phosphorus (4) for the stations shown (Sta.) and for the number of observations (No. obs.) per station

Sta.	(1) Part. -P $\mu\text{g-a/L}^*$	(1) No. obs.	(2) $\text{PO}_4\text{-P}$ $\mu\text{g-a/L}^*$	(2) No. obs.	(3) Org. -P $\mu\text{g-a/L}^*$	(3) No. obs.	(4) Diss. -P $\mu\text{g-a/L}^*$	(4) No. obs.
66	0.052	3	0.03	4	0.72	3	0.74	3
801	0.031	4	0.37	6	1.47	4	1.83	4
703	0.044	5	1.07	13	1.56	5	2.52	5
20	0.053	2	0.53	10	1.09	2	1.67	3
708	0.051	5	0.23	6	0.75	5	0.99	5
710	0.068	5	0.14	7	0.77	5	0.94	5
16	0.030	4	0.50	11	0.93	4	1.58	4
605	0.033	4	0.41	11	0.63	4	0.90	4
608	0.021	3	0.15	4	0.75	2	1.12	3
610	0.057	4	0.03	3	0.72	3	0.72	4
401	0.027	5	0.62	6	1.49	5	2.11	5
8	0.027	5	1.10	6	1.96	5	2.96	5
304	0.024	4	0.40	8	0.98	4	1.48	4
406	0.053	6	0.16	7	0.77	6	0.92	6
88	0.024	4	0.17	6	0.79	4	0.94	4

* To convert from microgram-atoms per liter to parts per million, multiply any phosphorus component by 0.031.

Table 9. Mean total phosphorus (1), nitrite-nitrogen (2), and nitrate-nitrogen (3) for the stations shown (Sta.) and for the number of observations (No. obs.) per station.

Sta.	(1) Total-P $\mu\text{g-a/L}^*$	(1) No. obs.	(2) $\text{NO}_2\text{-N}$ $\mu\text{g-a/L}^*$	(2) No. obs.	(3) $\text{NO}_3\text{-N}$ $\mu\text{g-a/L}^*$	(3) No. obs.
66	0.778	3	0.131	1	-----	-
801	1.856	4	0.318	2	5.88	1
703	2.562	5	0.410	3	15.70	2
20	1.878	2	0.324	2	12.50	1
708	1.043	5	0.233	2	9.30	2
710	1.010	5	0.114	2	5.09	2
16	1.613	4	0.483	3	14.40	2
605	0.935	4	0.170	2	7.60	1
808	1.138	3	0.271	2	9.51	1
610	0.727	4	0.214	3	8.07	2
401	2.137	5	0.301	3	14.00	2
8	2.987	5	0.279	2	23.00	1
304	1.500	4	0.546	2	-----	-
406	0.976	6	0.362	2	8.67	2
88	0.967	4	0.388	2	-----	-

Table 10. Zooplankton displacement volumes using the Clarke-Bumpus Sampler with number two net (aperture size 0.366 mm.)

Station	Mean volume ml/10,000 L	Number of observations
66	0.75	4
801	8.17	5
703	-----#	---#
20	1.31	9
708	1.18	6
710	2.04	4
16	1.93	10
605	2.65	7
608	2.15	4
610	2.95	3
401	3.54	5
304	4.46	5
406	4.03	6
8	9.01	5
88	6.02	3

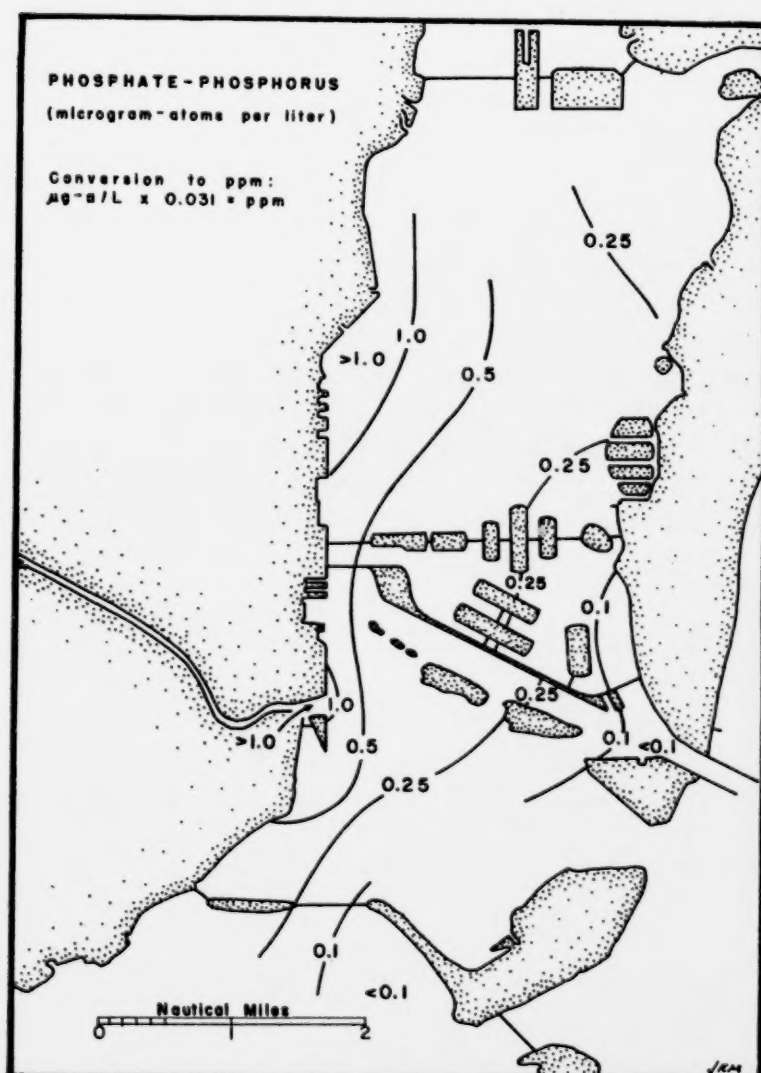


Figure 7. Horizontal distribution of average phosphate-phosphorus.

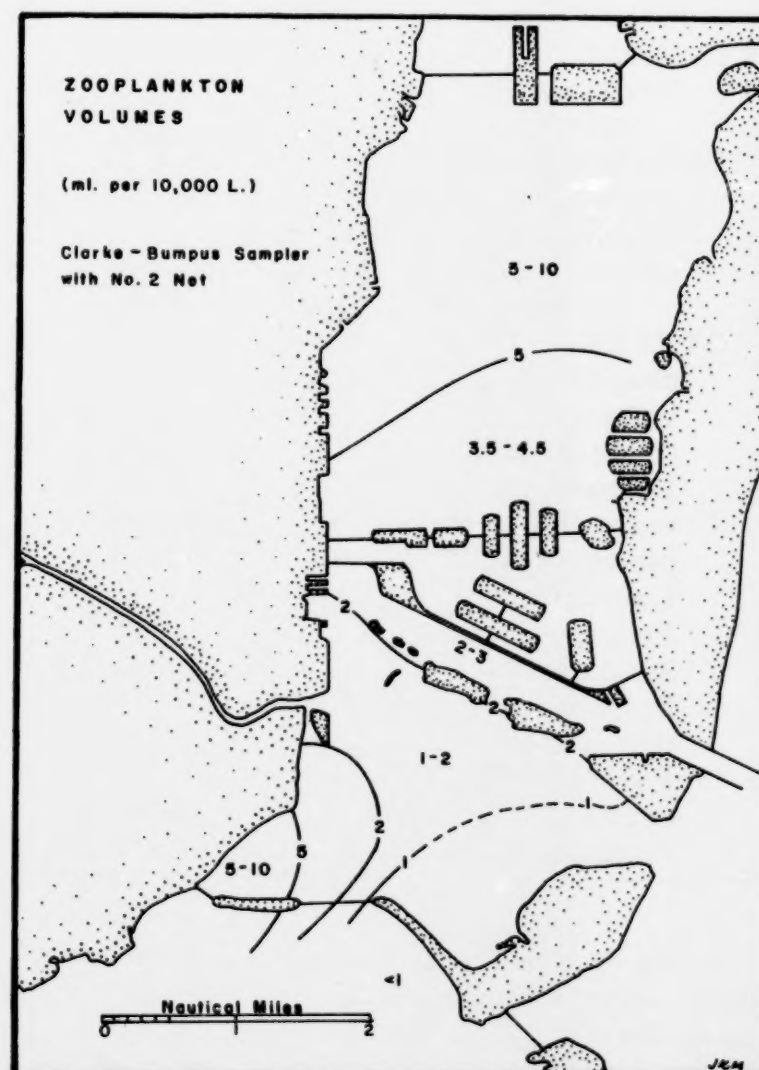


Figure 8. Horizontal distribution of average zooplankton volumes.

* To convert from microgram-atoms per liter to parts per million, multiply the phosphorus component by 0.031 and the nitrogen components by 0.014.

Samples consisted of mainly detritus.

representative plankton samples in order to estimate numbers per liter and numerical percentages by major groups. Results of the latter are summarized in Table 11, which shows that copepods comprised about 2/3 of the total number of zooplankters, chief of which were the calanoids. The most common species of calanoid copepods were *Paracalanus parvus* (Claus), *Acartia tonsa* Dana, and *Labidocera* sp. Giesbrecht (1892), Giesbrecht and Schmeil (1898), and Wilson (1932) were used for identifications.

Table 11. Percentages of major groups of zooplankton taken with No. 2 net (mesh aperture size 0.366 mm.).

Group	Percent
COPEPODS	
Calanoid	62.8
Cyclopoid	3.3
Herpacticoid	0.4
all copepods	66.5
DECAPOD LARVAE	
Anomura	13.5
Brachyura	1.8
other	5.0
all decapods	20.3
OTHERS	
nauplii	5.9
veligers	3.7
Chaetognatha	1.1
Leptomedusae	0.7
mosquito larvae	0.5
plutei	0.3
Larvacea	0.2
Pteropoda	0.2
Stomatopod larvae	0.1
Polychaete larvae	0.1
fish larvae	0.1
Foraminifera	0.1
Cladocera	0.1
Cumacea	0.1

In his discussion of the species taken in partially enclosed waters along Florida's east coast, Davis (1950) states that *A. tonsa* and *P. parvus* were the most common species. His station records show that both species were generally common at Beach Boat Slips and at Belle Isle, both near St. 406 of this study. Woodmansee (1949) did a seasonal study in a very shallow unpolluted portion of Biscayne Bay about 1/2 mile from the mainland shore some

11 miles southwesterly from the mouth of the Miami River. He found that *A. tonsa* was the most common copepod; *P. parvus* was second in abundance, was present throughout the year, and was most abundant from November to June, a portion of the year within which all plankton sampling of this study was done. The recent work of Lewis (1959) indicates that these species were common inshore plankters in 1958. These results suggest that *A. tonsa* and *P. parvus* tolerated sewage pollution in Biscayne Bay but have no sewage indicator value in this area because of their abundance in clean-water partially enclosed areas. It is particularly interesting to note that *A. tonsa* was the most abundant zooplankter taken by Ketchum, et al., (1952), in the Raritan River, and is the species upon which their estimates of predation mainly are based.

Numbers of zooplankters per liter were estimated by counting aliquots from the above seven samples. These fitted reasonably well a formulation of the type

$$Y = a + b \log X$$

in which Y is the number per liter and X is displacement volume (Figure 9). From data summarized in Table 10 it was estimated that the average displacement volumes for segments I, II and III were about 1.96, 2.46 and 5.81 ml/10,000 liters, respectively. Conversion to numbers per liter by the above relationship gave averages of 1.18, 1.30 and 1.77 zooplankters

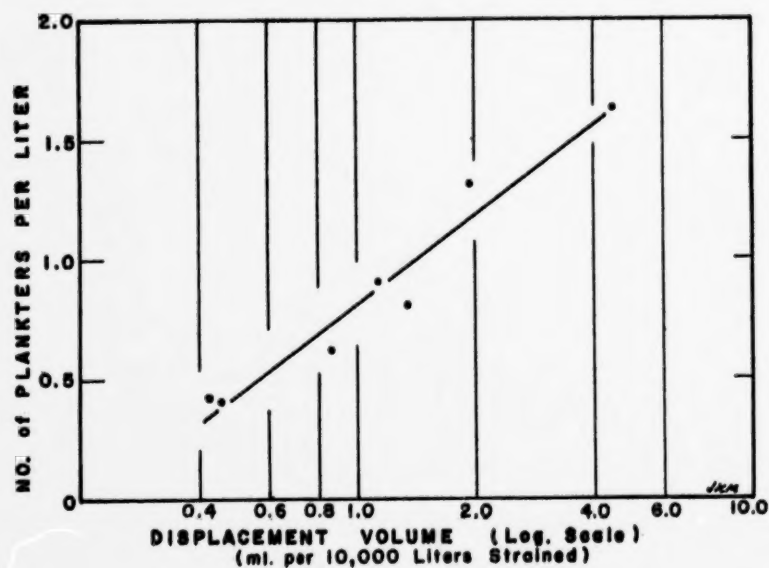


Figure 9. Comparison of displacement volumes and numbers of zooplankters per liter.

per liter for segments I, II and III, respectively. These densities are considerably less than those reported by Ketchum, *et al.*, for the Raritan River, and application of the same filtering factor per zooplankton per tidal cycle (10 ml.) gives negligible reduction of coliform bacteria in Biscayne Bay.

Water color observations have been summarized by simply tallying the number of times a given color was recorded in the field by visual observation. The color recorded most often has been taken as the predominant color at that station. Figure 10 shows the results. Color differences were very pronounced. The indicated zonation is roughly proportional to turbidity, the brown and dark brown areas along the Miami shoreline being much more turbid than the green and green-brown areas on the opposite side of the bay. This was partially due to wave action which was much more intense on the western side of the bay than on the eastern side due to the prevailing easterlies.

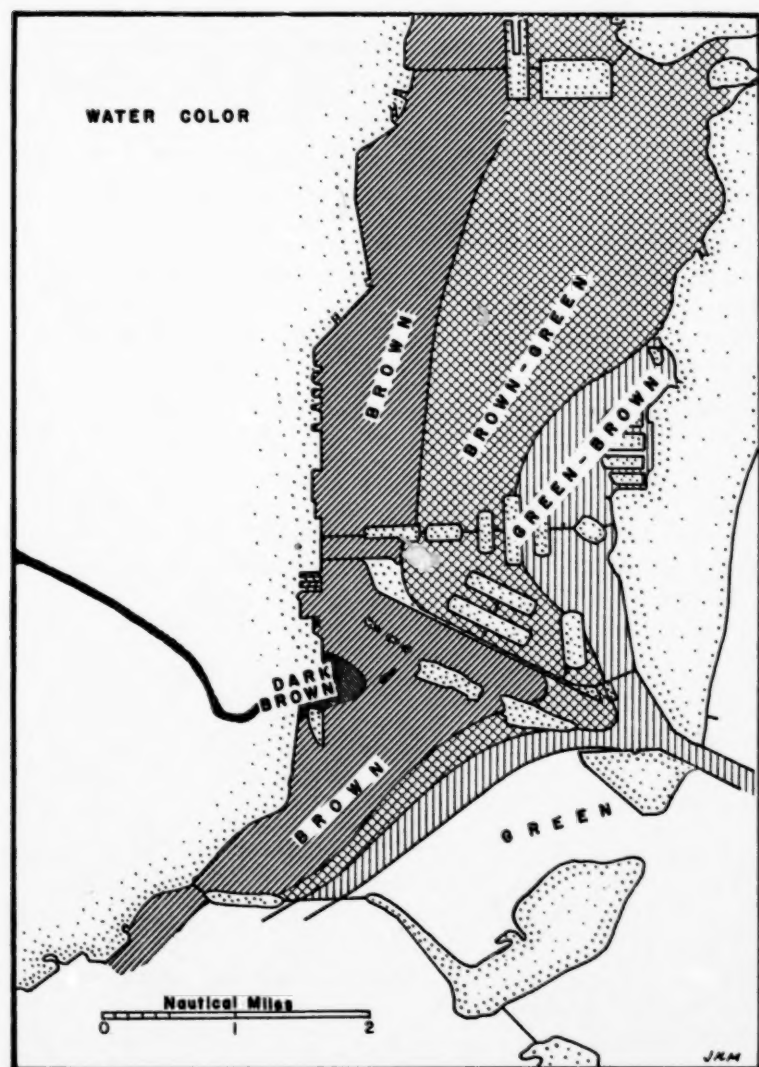


Figure 10. Horizontal distribution of average water color from visual field observations.

DISCUSSION

The above flushing calculations are made on the assumption that all fresh water came from the Miami River. The most important additional sources of fresh water are rainfall on the bay itself, rainfall on city streets thence by storm sewers to the bay, and ground water discharged through the aquifer along the bay bottom. Rainfall on that portion of the bay studied between December, 1953, and May, 1954, was about 4.39×10^8 ft.³, as averaged from Miami Beach and downtown Miami rainfall data (U. S. Weather Bureau, 1953-54). The Miami River discharge during this same period totalled approximately 134×10^8 ft.³. Thus, rainfall on the bay was about 3.3% of river discharge. Rainfall in the downtown Miami area during the same period totalled approximately 0.56×10^8 ft.³, or about 0.42% of river discharge. Ground water discharged through the aquifer along the bay bottom cannot now be adequately estimated. The local office of the U. S. Geological Survey has data which indicate discharge in the order of possibly 5% of river discharge in the study area, but these data are very tentative. It seems reasonable to conclude that the Miami River discharges at least 91% of the fresh water in the portion of the bay considered. For practical reasons, field work was not done on rainy days, so local rainfall had little effect on the results. This same consideration might apply in a limited way to ground water as well.

There were many sources of sewage other than the Miami River. Of a total of 70 outfalls, 29 emptied into the Miami River, 10 between Rickenbacker and Venetian Causeways, 24 between Venetian Causeway and Bay Point along the Miami shoreline, and 7 outside the study area. Due to the low intensity of flushing between Venetian Causeway and Bay Point, the 24 outfalls along this shoreline seem to have had little effect on calculations based on Miami River sewage alone provided that only Government Cut and adjacent areas were considered. As already discussed above and as indicated in Figure 6, the effect of proximity to sewage sources other than the Miami River is clearly shown at Stations 401, 801 and 8.

The above application of Ketchum's method produced an average MPN reduction of 352,000 to 7,900, a decrease of almost 98%. However, the final predicted MPN was about 4 times higher than the observed values. A similar result was

obtained by Ketchum, *et al.*, (1952), their final counts being 3 to 7 times the observed counts. Assuming reasonable accuracy for the flushing calculations, it appears that Ketchum's method gives a conservative, i. e., too high result. Depletion factors not included in the above calculations include adsorption and sedimentation, pre-

dation by the plankton which escape a No. 2 net, predation by benthic and fouling invertebrates, and competition for the limited food supply. These and other factors, including those reviewed by Greenberg (1956), remain essentially unevaluated quantitatively.

REFERENCES

- American Public Health Association. 1946. Standard methods for the examination of water and sewage. Ninth Edition. New York. xvii plus 286 pp.
- Austin, George B., Jr. 1954. On the circulation and tidal flushing of Mobile Bay. Alabama, part I. The Agricultural and Mechanical College of Texas, Dept. of Oceanography, College Station, Texas. Tech. Rept. No. 12. vii plus 28 pp. (Mimeographed).
- Bendschneider, Kenneth, and Rex J. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. University of Washington, Oceanographic Labs., Tech. Rept. No. 8, 18 pp.
- Clarke, George L. and D. F. Bumpus. 1940. The plankton sampler - an instrument for quantitative plankton investigations. Limnological Society of America. Special Publication No. 5. 8 pp., 5 Figures.
- Davis, Charles C. 1950. Observations of plankton taken in marine waters of Florida in 1947 and 1948. Quart. J. Fla. Acad. Sci., 12 (2): 67-103.
- Föyn, Ernst. 1951. Nitrogen determinations in sea-water. Rep. Norweg. Fish. Invest., 9(14): 1-7.
- Giesbrecht, Wilhelm. 1892. Systematik und faunistik der pelagischen Copepoden des Golfes von Neapel, etc. Fauna und Flora Neapel, 19, Text ix plus 831 pp., Atlas 54 Taf.
- Giesbrecht, Wilhelm, and O. Schmeil. 1898. Copepoda. I. Gymnoplea. Das Tierreich (Schulze), Lief. 6. Berlin. xvi. plus 169 pp., 31 Figures.
- Greenberg, Arnold E. 1956. Survival of enteric organisms in sea water. Publ. Health Rep., Wash., 71(1): 77-86.
- Hansen, Andrew L. and Rex J. Robinson. 1952. The determination and distribution of organic phosphorus in sea water. Part I. The determination of organic phosphorus in sea water with perchloric acid oxidation. Univ. of Washington, Oceanog. Labs., Tech. Rept. No. 10, 21 pp.
- Hela, Ilmo, Clarence A. Carpenter, Jr., and J. Kneeland McNulty. 1955. Water exchange studies. In Report on preliminary studies of pollution in Biscayne Bay. The Marine Laboratory, University of Miami, 55-3: I-1 -- I-27 (Mimeo.).
1957. Hydrography of a positive, shallow, tidal bar-built estuary (report on the hydrography of the polluted area of Biscayne Bay). Bull. Mar. Sci. Gulf and Carib., 7(1): 47-99.
- Ketchum, Bostwick H. 1950. The exchanges of fresh and salt waters in tidal estuaries. In Proceedings of the colloquium on the flushing of estuaries. Woods Hole Oc. Inst., Woods Hole, Mass., 50-37: 1-23 (Mimeo.).
1951. The exchanges of fresh and salt water in tidal estuaries. J. Mar. Res., 10(1): 18-38.
1955. Coliform bacteria and other pollutants in tidal estuaries. Sewage and Indust. Wastes, 27(11):1288-1296.
- Ketchum, Bostwick H., John C. Ayers and Ralph F. Vaccaro. 1952. Processes contributing to the decrease of coliform bacteria in a tidal estuary. Ecology, 33(2): 247-258.
- Lewis, Alan G. 1959. The vertical distribution of some in-shore copepods in relation to experimentally produced conditions of light and temperatures. Bull. Mar. Sci. Gulf and Carib., 9(1): 69-78.
- Minkin, Joseph L. 1949. Biscayne Bay pollution survey, May-October, 1949. Fla. State Bd. of Health, Bu. of San. Eng., Jacksonville, Fla. 78 pp. (Mimeo.).
- Morrill, John B., Jr., and F. C. W. Olson. 1955. Literature survey of the Biscayne Bay area. The Oceanog. Inst., Fla. State Univ., Tallahassee, Fla., 134 pp. (Mimeo.).
- Reynolds, Ernest S. 1955. Bacteriological studies. In Report on preliminary studies of pollution in Biscayne Bay. The Marine Laboratory, Univ. of Miami, 55-3: III-1 -- III-18 (Mimeo.).
- Robinson, Rex J., and Thomas G. Thompson. 1948. The determination of phosphates in sea water. J. Mar. Res., 7(1): 33-41.
- Smith, F. G. Walton, Robert H. Williams and Charles C. Davis. 1950. An ecological survey of the subtropical in-shore waters adjacent to Miami. Ecology, 31(1): 119-146.
- Theroux, Frank R. 1928. Pollution studies - Miami River and Biscayne Bay, Miami, Florida. Copy of report in files of Fla. State Bd. of Health, Jacksonville, Fla. 13 pp., 15 tables, 25 figs. (Typed).
- Tully, J. P. 1949. Oceanography and prediction of pulp mill pollution in Alberni Inlet. Bull. Fish. Res. Bd. Can., No. 83: 1-169.
- U. S. Weather Bureau. 1953-54. Special summaries, local climatological data, Miami and Miami Beach, Florida. U. S. Gov. Print. Off., Washington, D. C. Dec., 1953, through May, 1954.
- Wilson, Charles Branch. 1932. The copepods of the Woods Hole region Massachusetts. Bull. U. S. Nat. Mus., No. 158: 1-635, 41 pls.
- Woodmanssee, Robert A. 1949. The zooplankton off Chicken Key in Biscayne Bay, Florida. Unpublished Master's thesis, College of Arts and Sciences, Univ. of Miami, Coral Gables, Fla. 110 pp. (Typed).

SOME ASPECTS OF POLLUTION, PARASITISM AND INLET RESTRICTION IN THREE NEW JERSEY ESTUARIES

Thurlow C. Nelson, Biologist, New Jersey Division of Shell Fisheries,
Cape May Courthouse, New Jersey

ABSTRACT

Recent marked increases in population and industry in our maritime states have greatly added to pollution loads carried by coastal waters, coincident with much expanded needs of these waters for recreation. Evaluation of deleterious effects of foreign substances by bacteriological and chemical means is spasmodic and expensive. Instructive therefore is history of oysters, most sensitive biological indicators of conditions, and scientifically best known of all marine animals. Destruction of these bivalves in three New Jersey estuaries through man-induced and natural causes is presented. Raritan Bay, home of thriving oyster beds until World War I, when release of copper wastes destroyed larval oysters and rendered adults unsaleable. One famous oyster still survives in Navesink River closed by domestic pollution. Quahog or hard clams surviving in Raritan Bay are now threatened by oil in the mud bottom. Barnegat Bay, in colonial times, the chief source of seed oysters north of Chesapeake Bay, has been rendered unsuitable for oysters through stag-

nation resulting from progressive closure of Barnegat Inlet during the last half century. Inadequate and improperly placed jetties accentuate the condition. Delaware Bay, subject to storm damage on oyster beds, has suffered losses through mudworms and oyster crabs and is subject to continual ravages by blue crabs and oyster drills. Shipments in excess of 61,000 tons of shell oysters in 1921 and over \$5,000,000 worth of shucked oysters in 1928 was followed in 1929 - 1934 by a reduction from an average of 14,000,000 pounds of oyster meats annually, or 1/7th total for United States, to less than half. Chief cause was a reduction of the Delaware River discharge resulting in higher salinities favoring enemies. Losses in 1957 - 1958 aggregated in excess of \$3,000,000 from fungus disease the effects of which were accentuated by loss of food. Possible role of pollutants as cause of this loss and heavy mortality of seed oysters from D. D. T. mosquito spraying are discussed. Necessity for long and continuous study of estuaries is stressed.

Recent increases in population and industry in our maritime states greatly adding to pollution loads carried by coastal waters, have coincided with much expanded uses of these waters for recreation, and restrictions for the harvesting of shellfish. Evaluation of deleterious effects of these pollutants by bacteriological and chemical means is at best periodic, time consuming and expensive. Far more sensitive than many chemical tests may be reactions to these foreign substances of biological indicators living in the area, testing the water continuously seven days a week, at least six months a year. Such an indicator is our common oyster, Crassostrea virginica.

Thirty-nine years ago Dr. Austin H. Clark, Curator of Echinoderms in the U. S. National Museum, claimed that the oyster was scientifically the world's best known marine animal (2, 17). Since that date has been added much of what we now know of the physiological activities and ecological requirements of this most valuable of all estuarine animals. Important for our present

program is the striking sensitivity of this mollusc to the presence of minute amounts of dissolved substances in water passing through its gills. Observations in 1920 in New Jersey (13 B) and by Dr. H. F. Prytherch, Fish and Wildlife Service (28) in North Carolina, revealed substantial depression in activity of oysters during ebb tide discharge of water from swamps, although salinities are well above that which by itself would cause oysters to close. Hopkins, A. E. (5) found concentrations of sulfite pulp mill effluent as low as 0.5 part per thousand reduced by more than one-half the hours of activity of the Olympia oyster, Ostrea lurida, as compared with controls. Concentrations of acetylcholine 1/2,000,000 and of adrenalin 1/400,000 cause prompt contraction of gill musculature resulting in marked reduction of water pumpage in C. virginica (18). Advantages presented by oysters over other estuarine animals in evaluating effects of pollutants are the responses in diminished rates of water pumping, and in proportion of time during which the shell is opened. With an accurate method of measur-

ing water pumpage described in 1936 (16) quantitative results may be obtained. Hopkins (6) concluded that in the Pacific oyster, C. gigas: "The amount of water pumped at constant temperature is determined by the degree of openness of the shell". Since degree of openness of the shell and the amount of water pumped can both be measured continuously and automatically we have in the oyster a responsive test organism capable of yielding quantitative results in determining quality of estuarine waters.

Of major importance also is establishment of oyster pathology on a solid foundation during the past decade and a half through extensive researches supported by Project 9, Texas A. & M. Research Foundation (10). Through these comprehensive studies by S. H. Hopkins, J. G. Mackin and numerous associates we are now in a much better position to understand causes of numerous formerly unexplained mortalities of oysters. With this newly acquired knowledge plus substantial and ever increasing information on responses of the oyster to estuarine conditions, we now have in this mollusc our best biological indicator with which to evaluate relative roles of natural versus man-induced modifications of our brackish coastal waters. Our present task, therefore, is to attempt to separate effects of adverse conditions resulting from natural causes from those for which man has been responsible.

As a prelude to what follows, natural causes alone during late Cretaceous times some 60 million years ago destroyed over the seas of the earth the genera Exogyra and Gryphaea, two of the largest oysters the world has produced. In more recent times there is evidence that natural forces some 3000 to 4000 years ago destroyed a large and thriving oyster bed in what is now the Back Bay region of Boston, Mass. Excavation for a building revealed forty feet beneath the surface remains of an ancient fish weir which was in use by American Indians for over 300 years, during which extensive sets of oysters took place on stakes and wattle comprising the weir. At its uppermost level the weir suddenly stops, associated with large numbers of oyster shells with valves still attached, indicating burial during a severe storm possibly associated with cutting through a barrier beach with establishment of marine rather than estuarine conditions (19).

We shall now follow the history of oyster production over a period of more than half a

century in three New Jersey estuaries: Raritan Bay, Delaware Bay, and Barnegat Bay. The first two are large funnel shaped bays widely open to the Atlantic Ocean, with large tidal ebb and flow, and subject to substantial disturbance of the bottom during heavy storms. Barnegat Bay is a narrow estuary, 30 miles in length, connecting with the ocean through Barnegat Inlet, with Bay Head - Manasquan Canal on the north, Little Egg Harbor on the south. The latter opens to the ocean at its southern end through two closely adjacent inlets with tidal range from 1.8 feet at Manahawken Bridge, southern end of Barnegat Bay, to 3.1 feet at its lower end. Little Egg Harbor was formerly an important oyster producing area, and here in 1916 was made the first survey of distribution of oyster larvae in this country (13 A). Three years later a heavy storm cut through a second inlet, salinities rose, resulting in rapid elimination of oysters except for scattered groups in tidal creeks entering the Bay, but with corresponding increase in production of quahogs or hard clams, Mercenaria mercenaria. Little Egg Harbor now supports one of the most productive clamming areas of the New Jersey coast. Since scientific studies in the area had been in progress there since 1913 a substantial background of scientific data was available with which to compare changes which followed breaking through of the second inlet. Barnegat Bay with its greatly restricted inlet through a barrier beach has a tidal range of but 6 to 8 inches in marked contrast to ranges in the two funnel shaped estuaries, Raritan Bay, with 5 to 6 feet, Delaware Bay with 5 to 7 feet.

Early references to extent and importance of oyster fisheries in these New Jersey bays are found in the monograph of Ernest Ingersoll on the "Oyster Industry", part of the Tenth Census of the United States, published in 1881 (7). An early reference here to oysters in Raritan Bay is that of Sir George Carteret in 1681: "And at Amboy Point and several other places there is abundance of brave oysters. Oysters, I think, would serve all England". Accounts of travels of Peter Kalm, 1748, referring to abundance and quality of these oysters observed: "In their quality they are exceeded by those of no country whatsoever. People of all ranks amongst us in general prefer them to any other kind of food. Nor is anything wanting save a little of the fillings of copper to render them equally relishing even to an English palate, with the best from Colchester". This last in view of subsequent

fate of these oysters is of particular interest, as recorded below.

Ingersoll notes that growth of oysters in Raritan Bay, then called New York Bay: "is reasonably rapid though not as fast as in Great South Bay, Long Island. Left for three years, shifted in spring, sold in the fall. Native seed outgrows 'foreign' seed, doubling in size in a single season". Reference to more rapid growth of oysters in Great South Bay is of particular interest in view of the subsequent history of this famous oyster producing area, home of the original Blue Points. Closure of Moriches Inlet at the eastern end, progressive restriction of Fire Island Inlet at its western end, together with heavy over fertilization from duck farms on the watershed produced some stagnation and undesirable plankton that all but wiped out the oyster industry of Great South Bay, Long Island (29, 30).

Oyster Research in New Jersey was initiated by my father, the late Dr. Julius Nelson of Rutgers College in 1888. Until 1900 his studies were confined to the Raritan Bay area. His first report, 1899 (12) records shipment of 30,000 bushels of seed oysters to California in 1886 by the J. and J. W. Elsworth Company, of which 27,000 came from Newark Bay; 3,000 from natural beds in lower Raritan River. For our next account of conditions here we pass to the second comprehensive study of pollution of shellfish bearing areas by the United States Public Health Service: "Investigation of the Pollution of Certain Tidal Waters of New Jersey, New York, and Delaware With Especial Reference to Bathing Beaches and Shellfish Bearing Areas" by Surgeon Hugh S. Cumming, subsequently Surgeon General of the Service, conducted in 1915, published 1917 (4). The first study, also by Surgeon Cumming with able assistance of W. C. Purdy and Homer P. Ritter was carried out in 1913, published 1916. "Investigation of the Pollution and Sanitary Conditions of the Potomac Watershed With Special Reference to Self Purification and the Sanitary Condition of Shellfish in the Lower Potomac River (3). These two outstanding researches in this field resulted from an Act of the Congress approved August 14, 1912, providing among other things that the Public Health Service study: "the pollution direct or indirect of the navigable waters of the United States".

Figure 1 of the Raritan Bay Report shows shellfish bearing areas which were investigated

in 1915. Symbols for water and oyster sampling stations and for sewer outfalls are designated hereon. Those for oyster sampling stations indicate locations of beds of market oysters. Not shown hereon are oyster seed beds in Newark Bay and in mouth of Raritan River to the left of the margin on this map. Indicated also is outfall of the new Raritan Valley Trunk Sewer.

These two Surveys by Surgeon Hugh S. Cumming and associates are outstanding contributions to the knowledge of the effects of domestic pollution on bacterial loads of shellfish bearing and bathing waters. They tell us nothing however of industrial effluents harmful to estuarine



Figure 1. Map 1 of Raritan Bay, Sandy Hook Bay, Newark Bay, and New York Upper and Lower Bays, showing location of oyster and water sampling stations and sewer outfalls. Numerous small symbols for sewer outfalls are concentrated at the extreme left near the mouth of Raritan River. A single larger symbol, circle with cross, immediately to left of R of Raritan Bay has been added to show location of outfall of the Raritan Valley Trunk Sewer. From Cumming, H. S., 1917, Citation 4.

life entering our coastal waters along with domestic wastes. In the same year, 1915, that Surgeon Cumming and staff were determining bacterial qualities of these shellfish bearing waters, Dr. Julius Nelson in his final report described the condition of the oysters which led to their extinction within the next two years (12 A). His report reveals by colorimetric test 40 milligrams of metallic copper per oyster for blue bivalves from this bay as against 9 mg. for uncolored ones. With electrolytic methods corresponding figures were 18.7 and 3.5 mg. respectively. In the next year I observed an 8 - 10 inch stream of deep brown waste flowing from a large copper refinery at Perth Amboy within less than a mile from oyster beds of the upper bay. By 1917 the J. and J. W. Elsworth Company, largest lease holder in the area made its final shelling in an effort to secure a set of oysters, following which their operations were transferred to the outer end of Long Island and to Barnegat Bay. In the Report of the New Jersey Board of Shell Fisheries for 1917, Director George A. Mott describes the final efforts to clean up the leased grounds in hopes of a set (11). He notes that: "...not long since the oyster business of Raritan Bay was in flourishing condition but because of the flow of trade waste into the streams, sound and bays of that locality, and other causes (Government dredging, dumping of stone ballast, cinders and ashes and other numerous wastes) the natural supply of seed oysters has become depleted...".

Although Dr. Herbert Prytherch, Fish and Wildlife Service, (27), held that the heaviest setting of oyster larvae occurred at concentrations of 0.15 mg. to 0.5 mg. copper per liter with cessation of setting with a copper content less than 0.01 mg. per liter. Dr. E. P. Churchill, also of the Fish and Wildlife Service, in unpublished results found lethal effects upon oyster larvae of copper in concentrations found in certain of our harbors. No one to date has confirmed Prytherch's claims in 1931 and 1934 as to the necessity for copper in the setting of oysters. Oysters and other molluscan shellfish are known to store large quantities of heavy metals, a fact which gives great concern to our oyster growers as they contemplate possible escape of radioactive metals of long life into our coastal waters. Whether copper caused the disappearance of oysters from Raritan Bay or whether this resulted from the combined effects of many industrial wastes, there exists today in the Navesink River, a tributary to this Bay,

an area closed to oyster culture because of heavy pollution by domestic sewage, a thriving bed of large white oysters showing none of the discoloration characteristic of former oysters in the Amboy area, and which are still reproducing. It is with oysters from this river that Dr. Julius Nelson began his researches in 1888. Ingersoll, quoting Lockwood, 1872, called these "Emperors of the Bivalves".

In contrast to the disappearance of oysters in Raritan Bay has been the persistence here to this day of a substantial fishery for the quahog or hard clam. Living in water of higher salinity than oysters, hence farther removed from the source of copper pollution, these bivalves did not take on the marked discoloration of the oysters. In recent years, however, a progressive increase of oil in mud of the bottom has interfered with sale of these shellfish. In January 1958 the Raritan Valley Trunk Sewer began operations. By the following summer marked increase in numbers of marine species and their ranges into the lower Raritan River had already taken place, associated primarily with increase in dissolved oxygen (8). From evidence now available it is believed that cessation of setting and destruction of oysters in Raritan Bay was due primarily to high concentrations of copper wastes in these waters.

Moving now to Barnegat Bay we find a long narrow estuary which at no time has received any industrial waste, and only small discharges of well treated domestic wastes within recent years. During most of the 19th century the 10 mile long Cedar Creek natural oyster beds supported a heavy fishery, many boats coming from New York and from Raritan Bay. Until about 1812 this Bay had two inlets direct to the ocean, Cranberry Inlet opposite the mouth of Toms River and Barnegat Inlet farther south. Geological evidence indicates that for probably two centuries prior to closure of Cranberry Inlet Barnegat Inlet remained essentially stationary, but during the last century it has migrated approximately a mile to the south (9). On my first visit to this Inlet fifty-three years ago it was safely navigable, while a substantial beach lay between the Inlet and famous Barnegat Light.

As littoral drift from the north encroached upon the Inlet, corresponding quantities of sand were removed from the southern bank until erosion threatened the lighthouse. Owing to its historical interest local residents raised sub-

stantial sums for its protection, thus halting further southward migration of this point. The north point, however, continued to advance in spite of a jetty placed by the Army Engineers, resulting in progressive restriction of the gorge of the Inlet (22, 23, 24).

Meanwhile the highly productive ten mile Cedar Creek natural oyster bed had been greatly depleted due to failure to maintain spawning oysters and clean shells to catch each season's crop of young oysters. Researches begun here in 1921, however, showed the area to be a natural trap for oyster larvae; hence local oystermen and two large oyster planting firms from Long Island Sound leased substantial portions of the bottom with maximum of 2400 acres held by 1924. Two young men just out of college invested \$400 in shells in that year, sold a portion of the seed oysters thereon ten months later for \$1450 (13 C). In 1925 over 200,000 bushels of shells were planted and a heavy set up to 1000 spat per shell was obtained. Within a week all of this had died, as had a set of similar intensity the year before in Great South Bay, Long Island (13 D). In both cases stagnation due to restricted inlets at Barnegat and Fire Island Inlets resulted in deficient oxygen in bottom waters causing death of the newly attached oysters. Only one of the four gill plates of older oysters is present at attachment of the larva, hence newly attached spat are particularly vulnerable to low oxygen during their early life on the bottom.

Faulty placing of jetties at Barnegat Inlet interferes with natural flow of ebb tide which under effects of Coreoli's Force formerly swung sharply to the right in passing out the Inlet. Meanwhile littoral drift from the north continues to pass sand over the north jetty into the Inlet gorge whence it is transported into two "stilling basins", one located between the jetties, the other just inside of the gorge (22). Except for a few oysters in two of the rivers entering Barnegat Bay this mollusc has now disappeared from an area which a century ago was probably the largest and most productive natural oyster bed on the Atlantic coast north of Chesapeake Bay. Plan of a new inlet has been published through which it is believed that some portion of this once great oyster resource might be restored (23, 24). We must however, ever face at Barnegat Inlet, at Fire Island Inlet, Long Island, and at many others throughout the world, the well supported conclusion of Colonel Earl I. Brown, U. S. Army Engineers in 1928, that

inlets on sandy coasts tend to destroy themselves (1). Briefly, his central theme is that with the greater velocity of flood tide currents than during the ebb, more littoral drift will be carried through the inlet to be deposited within the bay than will be removed during subsequent ebb tides. The history of Barnegat Inlet shows that where the inlet is free to shift in direction of the drift, accumulated sand is left behind, with ebb tides ever cutting new and adequate channels, hence death may be long postponed. Once migration is halted by defensive works however, the inlet chokes to death with the sand flats it has piled up behind itself in the bay, Figure 2, (23, 24).

We pass finally to Delaware Bay, former home of one of the most productive oyster industries in the world. From two ports at the mouth of the Maurice River there were shipped during the season of 1920-21 more than 61,000 tons of oysters in the shell. In 1928 annual tax

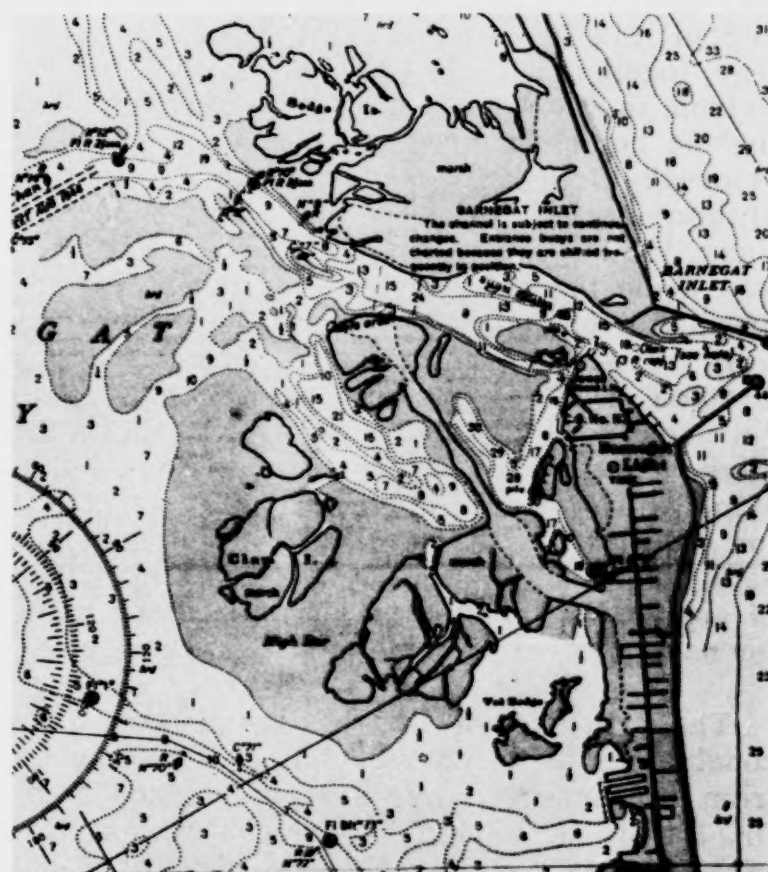


Figure 2. Barnegat Inlet, New Jersey, from Map 1218, U. S. Coast & Geodetic Survey corrected to August 1958. Conspicuous feature is the immense amount of sand from the littoral drift carried through the Inlet by flood tides and deposited as flats in Barnegat Bay. Note 2 foot depth, mean low water, at entrance between the jetties.

was paid into the local association on more than five million dollars worth mostly of shucked oysters. The decade 1920-29 may well be called the golden age of the industry when it was supplying an average of some 14 million pounds for the entire United States. During this period natural, economic and political conditions were kind and the oyster planters prospered.

Faced in 1929 with the diversion of 600 million gallons daily from the headwaters of the Delaware river by New York City, the State of New Jersey sued the State and City of New York in the United States Supreme Court to enjoin the diversion. The historic decree of Justice Holmes in 1931 upheld finding of the Special Master that diversion of more than 440 mgd would result in greater damage to the oyster industry of Delaware Bay than the State of New Jersey should be called upon to bear under the principle of equitable apportionment of the waters of the Delaware River. Since the writer was appointed Biologist to the New Jersey Board of Shell Fisheries July 1, 1920, it was his privilege, together with his brother, Mr. J. Richards Nelson, to study the biology of this estuary during the period of prosperity and to establish before the Court the role of river flow in the life of the oyster. In the Second Delaware Diversion Case, 1952-54, settled by stipulation, a bargain was made through which in exchange for increased diversion up to 800 mgd the City of New York agreed to maintain a minimum flow at Trenton of 3400 cubic feet per second through releases from impounding reservoirs within the State. New Jersey is permitted to divert up to 1 mgd through the Delaware and Raritan Canal for industrial and potable use with no compensating releases of stored water since diversion of approximately this amount was being made for navigation at the time of the first suit.

The writer for the second time presented his conclusions as to damage which would result from this increased diversion, ably seconded by Dr. Harold H. Haskin, Oceanographer of Rutgers, the State University, who estimated that withholding 800 mgd would result in shifting the zone of destruction caused by the oyster's worst enemy, the oyster drills, by 0.8 mile upstream on the natural seed beds in the upper bay. Maintenance of the minimum flow aids industries of the lower river through holding back advance of salt water during dry periods. The fallacy of supposed benefits to the oyster industry from this equalizing of river discharge is dramati-

cally illustrated when we compare the total additional water released during the five months, May through September, of greatest activity and need of the oyster for fresh water flow, with the amount of water withheld from the river in storage during those same five months. Had the New York plan of release established by decree of the Court been in operation during these five months of the dry year 1931 there would have been released from storage 2.77 billion cubic feet of water. During the same period, however, there would have been withheld from existing flows 20.57 billion cubic feet, thus robbing the oyster industry of a net of 17.8 billion cubic feet which would otherwise have flowed down into Delaware Bay.

It is true that in this same year during October and November release of stored water during these two months would have exceeded considerably the amounts withheld from stream flows, but owing to lag in time in reaching the oyster beds it would have arrived too late to be of appreciable help. September is the month of greatest destruction by oyster drills in Delaware Bay, damage from which frequently has exceeded one million dollars annually. It is also the month during which oysters depend most heavily upon nutrients in stream flows to supply substances required for plankton used by oysters to restore tissues exhausted during summer spawning.

In the very month, May 1931, in which Justice Holmes rendered his historic decision in the First Delaware Diversion Case, nature was already well on her way toward substantiating the claims of New Jersey regarding needs of the oysters for the flow of the Delaware River. The driest year of record in New Jersey, 1930, was preceded and followed by one with sub-normal rainfall, in all a period of four years which included also the second driest year and one of the four driest years of record. Increased salinity permitted invasion of the upper bay natural seed beds by oyster drills and by other enemies. Within two years oyster production fell from an average of 14 million pounds of meats annually to one-half that amount. A hurricane in August 1932 followed by heavy winter northeast gales caused serious losses of planted oysters. Heavy wave action sweeping in from the sea broke up the crust of prepared bottoms permitting oysters to sink into soft mud beneath. This has ever been a hazard in Delaware Bay; in 1909 my father was called to the area to

determine the cause of extensive mortality on certain grounds. As described in his report for that year he found that strong prevailing winds from one quarter set up currents of sufficient strength to transport sand and mud from one side of the area to the other burying many oysters. With comparable winds from the opposite direction materials were shifted back again, burying oysters which in the meantime had been planted on hard bottoms (12 B).

In 1940 a new hazard appeared with the invasion of the oyster grounds by great hordes of the mudworm Polydora ligni. This associate of the oyster has probably always been present in the area, but with unusually favorable conditions of heavy early spring spawning produced a very much larger population than usual. This worm feeds on plankton collected in heavy, viscous mucus secreted from its peristomial cirri. Rejected mud held firmly in a matrix of stiff mucus soon covered oyster beds to a depth of several inches. With exclusion of oxygen beneath this film, sulfate reducing bacteria produced large amounts of hydrogen sulfide. This killed oysters first in the deeper sloughs, decomposing oysters adding to oxygen demand, with death both to worms and oysters sweeping across the beds. On certain areas the oysters were virtually wiped out (26).

Taking advantage of dredging operations by Army Engineers in the main ship channel, an agitator, quite appropriately with the name of Quirk, persuaded a few of the oyster growers to contribute several hundred dollars to a fund with the purpose of suing the Army Engineers for damages wrought by the mud worms. Fortunately for all concerned, evidence gathered by Dr. L. A. Stauber, resident biologist of the Oyster Research Laboratory, convinced a majority of the oyster planters of the real source of their difficulty. It is of interest in this connection that subsequent to 1888 invasion of oyster beds of Australia by the mud worm, Polydora ciliata, destroyed all oysters on the bottom. The industry now is confined to the intertidal zone with oysters growing attached to slabs of stone or to logs raised above the bottom. Any oysters lying on the bottom are soon destroyed by mud accumulated within the shell cavity by the mud worm (31).

In 1941-42 a second associate of the oyster, Pinnotheres ostreum, the soft pink oyster crab found within the shell cavity, suddenly increased

greatly in numbers. In one oyster Dr. Stauber counted 262 first stage young of this crab. Known since days of Pliny the Elder, 23-79 A.D., this associate has always been considered as a harmless commensal, a mess mate living on materials rejected from the oyster's gills. Now for the first time in recorded history this associate was found to seriously erode the oyster's gills, destroying the marginal food conducting furrows which bring material to the palps for transmission to the mouth (32). By a rough estimate at least a third of a million dollars worth of oysters died as a result of the abundance and change of habits of this formerly harmless commensal.

The spring of 1957 ushered in a third and far more devastating destruction of oysters in Delaware Bay. Between mid-April to late May oysters died rapidly over extensive areas of the planted grounds. Sampling in June revealed losses from 70 to 85 percent at the center of destruction grading off to 35 percent on outlying beds. Chief symptom of the disease is a marked shrinkage with brown discoloration of the meat. Reduction in meat volume to as much as one-eleventh the capacity of shell cavity has been recorded. Prepared sections reveal a great abundance of leucocytes, but owing to marked shrinkage of tissues it is not yet clear whether these cells have materially increased in numbers, or are the original cells crowded into the greatly reduced tissues. The causative organism thus far associated with the disease is possibly one of the lower fungi, but recent demonstration of rapid death through injection of bacteria cultured from dying oysters raised doubt whether the larger organism is by itself the sole cause of death. In two years losses to the oyster growers from this mortality is in excess of three million dollars. The death rate has materially decreased in 1959 raising hopes that ultimately from immune survivors a new resistant population may be built up. Such has been the history following a severe epidemic of similar nature on oyster beds of Prince Edward Island, Canada (33, 34, 35).

Concern is felt by estuarine ecologists in this and in other oyster producing areas of the country as to possible contributory roles to our recent and continuing oyster mortality played by foreign substances brought down to the bay from industrial activities, insecticides used on farms and in mosquito control, together with many other foreign substances now entering our

coastal waters. We are assured by sanitarians that the Delaware River is now in better condition bacteriologically and in oxygen content than it has been for the past quarter of a century. The question at once arises, however, may this not be due in part at least to bactericidal effects of foreign substances which while reducing bacterial loads are striking at the very foundations of all important food cycles of the oyster and of other estuarine organisms? At onset of our oyster mortality in the spring of 1957 chlorophyll determinations revealed but one-tenth the usual amounts of this all important indicator of plankton content of water over the beds. Likewise the striking richness of bottom diatoms and of associated organisms on the Cape May tidal flats which we have followed since 1928 has disappeared. Formerly we have seen these flats, especially in the fall, turn brown like the frosting on a chocolate cake as the tide ebbed away and the diatoms moved up to the surface of the sand mud flats to form a mat a millimeter or more in thickness. During the past summer following shortly upon heavy spraying of DDT on adjacent marshland draining over these flats, heavy sets of oysters on shells in some 4,000 bags were destroyed.

There is much more which might be presented here, but experience of thirty years in this bay added to forty years of studies in other oyster producing areas of New Jersey and elsewhere by

Dr. Julius Nelson, by Drs. Stauber and Haskin, and by the writer and associates, point to the all important significance of long continued studies carried on in our estuaries. These are unquestionably the most complex aquatic environments in the entire world, forever changing with each tidal cycle, subjected to alternate floods and droughts, severe wave action, and now at last threatened by a host of foreign substances released into our rivers. Only through such long time studies can we establish the usual conditions in these waters, but far more important record the extremes which occasionally do occur with devastating effects. Let it ever be emphasized that: first, existence of plants and animals is determined by the extremes of environmental stresses hence mean river flows and mean temperatures are of little significance, especially when winter months are included. Second: the true measure of effects of foreign substances can be accurately determined only after extended periods of time and by measuring their effects on reproductive activities of aquatic forms, on their larvae, and upon the food chains essential to both young and adult stages. In the battle to preserve purity of our coastal waters the estuarine ecologist will need facts gathered from virtually every field of biology, together with much of chemistry; he will need the best training our universities can give him.

REFERENCES

1. Brown, Col. Earl I. 1928. Inlets on sandy coasts. Proc. Am. Soc. Civil Eng. 54, Pt. 2 February.
2. Clark, A. H. 1920. The Smithsonian Institution, its functions and its future. Science, 63: 147-157.
3. Cumming, H. S., W. C. Purdy, and H. C. Ritter. 1916. Investigation of pollution and sanitary conditions of the Potomac watershed with special reference to self purification and sanitary condition of shellfish in the lower Potomac River. Bull. 104, Hygienic Lab., U. S. Public Health Service. 239 pp.
4. Cumming, H. S. 1917. Investigation of the pollution of certain tidal waters of New Jersey, New York, and Delaware with special reference to bathing beaches and shellfish bearing areas. Public Health Bulletin 86, U. S. Pub. Health Serv., 150 pp.
5. Hopkins, A. E., P. S. Galtsoff, and H. C. McMillin. 1931. Effects of pulp mill pollution on oysters. Bull. U. S. Bur. Fish. 47: 125-186.
6. Hopkins, A. E. 1933. Experiments on the feeding behavior of the oyster. *Ostrea gigas*. J. Exp. Zool. 64: 469-494.
7. Ingersoll, E. 1881. The oyster industry. In: The history and present condition of the fisheries industries. Tenth Census of the United States, 250 pp.
8. Jeffries, Harry P. 1959. The plankton of Raritan Bay. Ph. D. thesis, unpublished, Rutgers University Library, New Brunswick, New Jersey.
9. Lucke, J. B. 1934. A study of Barnegat Inlet, New Jersey, and related shore line phenomena. Ph. D. thesis, Princeton University. Shore and Beach II: (2) 1-34.
10. Mackin, J. G., Hopkins, S. H. et al. 1950-1958. Twenty papers on pests, parasites and pathology of diseases of oysters. Texas A. & M. College and Project 9, Research Foundation. In Annual Proceedings, National Shellfisheries Association.
11. Mott, George A. 1918. Report of New Jersey Board of Shell Fisheries for 1917. 53 pp. Trenton, N. J.
12. Nelson, Julius, 1909, 1916. Reports of Dept. of Biology, N. J. Agr. Expt. Sta., 12 A for 1915; 239-260. 12 B for 1909; 225-266. Rutgers University, New Brunswick, N. J.

13. Nelson, Thurlow C. 1917-1927. Reports of Dept. of Biology, N.J. Agr. Expt. Sta. 13 A for 1916: 401-430; 13 B for 1920: 319-349; 13 C for 1925: 281-288; 13 D for 1926: 103-113.
14. _____ 1921. Some aspects of pollution as affecting oyster propagation. Am. J. Pub. Health 11, 498-501.
15. _____ 1923. Industrial pollution and oyster propagation. Seventh Ann. Conv. Central Atlantic States Assoc, Am. Dairy, Food and Drug Officials. Apr. 23-25. Washington, D.C.
16. _____ 1936. Water filtration by the oyster and a new hormone effect upon the rate of flow. Proc. Soc. Exp. Biol. & Med. 34: 189-190.
17. _____ 1938. The feeding mechanism of the oyster. Jour. Morph. 63: 1-61.
18. _____ 1941. On the locus of action of diantlin upon the oyster's gills as revealed by effects of acetylcholine, eserine, and adrenalin. (abs.) Anat. Rec. 81: 88.
19. _____ 1942. The Oysters. Chapt. 3 of The Boylston Street Fishweir: 49-64. Robt. S. Peabody Fdn. for Archeology, Phillips Acad., Andover, Mass.
20. _____ 1947. Some contributions from the land in determining conditions of life in the sea. Symposium of Marine Ecology. Ecol. Monogr. 17: 337-346.
21. _____ 1953. Some aspects of water movements and shore erosion in relation to mosquito control in tidal areas. 1953 Proc. N.J. Mosquito Ext. Assoc. 57-63.
22. _____ 1954. We must save Barnegat Inlet. N.J. County Government, Jan. 54: 12-17. Trenton.
23. _____ 1956. Barnegat Bay must have an adequate inlet. N.J. County Government, 10-11, 14-15, 21-24.
24. _____ 1959. New entrances for Barnegat Bay and Island Beach State Park. N.J. County Government, (In Press).
25. _____ 1959. Oyster seed production on Cape May's tidal flats. 13th Ann. Bull. Cape May Geogr. Soc., 12-16.
26. Nelson, T.C. and L.A. Stauber. 1950. Observations of some common polychaetes on New Jersey oyster beds with especial reference to Polydora. (Abs.) Anat. Rec. 78: 102-103.
27. Prytherch, H.F. 1934. The role of copper in setting, metamorphosis, and distribution of the American oyster, Ostrea virginica. Ecol. Monogr. 4: 47-107.
28. _____ 1945. Personal communication.
29. Redfield, A.C. 1951. Report on a survey of hydrography of Great South Bay made during summer of 1951 for the town of Islip, N.Y. 30 pp. Woods Hole Oceanographic Inst., Mass.
30. _____ 1952. Report to the towns of Brookhaven and Islip, N.Y. on hydrography of Great South Bay and Moriches Bay. 80 pp., Woods Hole Oceanography Inst. Mass.
31. Roughley, T.C. 1922. Oyster culture on the George's River, New South Wales. Tech. Ed. Ser. No. 25: 47 pp., Technological Museum. Sydney.
32. Stauber, L.A. 1945. Pinnotheres ostreum, parasitic on the American oyster, Ostrea virginica. Biol. Bull. 88: 269-291.
33. Logie, R.R. 1957. Epidemic oyster disease in New Brunswick and Nova Scotia. Paper read at National Shell Fisheries Convention, New York, July, 1957. (Unpublished).
34. Medcof, J.C. 1958. The epidemic oyster disease and rehabilitation transfers in 1957. General Series Circular No. 31, Fisheries Reserach Bd., Canada.
35. _____ 1958. Oysterman's disaster. Gen. Ser. Circ. No. 32. Fish. Res. Bd., Canada.

MARINE POLLUTION PROBLEMS IN THE NORTH ATLANTIC AREA

Bostwick H. Ketchum - Woods Hole Oceanographic Institution^{1/}
Woods Hole, Massachusetts

INTRODUCTION

In discussing the "Marine Pollution Problems in the North Atlantic Area" I want to emphasize the basic problems involved in the disposal of wastes in estuaries and coastal waters. No effort will be made to discuss in detail the problems which are approaching solution in the North Atlantic area or those problems which are still serious and will require solution in the future. However, examples will be drawn from the area to illustrate the principles which must be considered in evaluating pollution of marine waters.

The North Atlantic area is characterized by having several large rivers, with important estuaries. Dense centers of population have developed on the shores of each of these estuaries. Traditionally the marine resources of the area have been important, and numerous people living along the coast depend upon the income from harvesting shellfish and finfish. There has been and continues to be, therefore, a dispute over the optimum use for these marine waters. The fishing interests rightfully feel that, in the past, pollution has destroyed many of the natural resources, and they vigorously oppose encroachment by waste disposal into those waters which are presently supporting the important marine populations.

Considerable progress has been made, of course, in the purification of domestic and industrial wastes. Investigations are also being made of the advisability of moving seaward the outfalls of sewers in order to reduce pollution of the landward parts of estuaries. This has been done in the city of Boston and in the Raritan Valley. Moving the outfall outside of the estuaries to the coastal waters would dispose of sewage in areas where the volume of water available for dilution is maximal and where the

opportunities for return to the estuary is minimal. The cost of long outfalls needed would be large and sometimes prohibitive. The same result has been achieved in several cases by barging the waste materials to sea for disposal. Thus the sludge of the treatment plants of New York City are barged to sea and disposed offshore, small quantities of radioactive wastes are disposed offshore near Boston, and quite large quantities of industrial wastes are barged to sea off New York.

In this review I would like to discuss briefly the effect of the locations of an outfall within an estuary in terms of the dilution potential available and to introduce some of the problems involved in evaluating the disposal of liquid wastes at sea.

DISTRIBUTION WITHIN AN ESTUARY

Within an estuary a variety of locations may be available for a sewer outfall. The net seaward flow at all locations is the same, since this is determined solely by the amount of river water being added at the landward end. However, the amount of sea water entrained in this river flow, and consequently the total volume available for dilution, increases progressively in the seaward direction. This does not increase the net flow since the amount of sea water leaving with the fresh water is balanced by an equal amount of sea water entering on the flooding tide.

The amount of dilution which is to be expected for any locality and the distribution of a conservative pollutant can be evaluated through a study of the salinity distribution in the estuary. Each sample of water is a mixture of river water and sea water, and from the salinity the proportion of each in the mixture can be determined. The

^{1/}Contribution No. 1035.

average distribution of a pollutant in the estuary can be derived from the salinity distribution, since the pollutant is subject to the same mixing processes as the fresh and salt waters. At and near the outfall location, the pollutant concentration will obviously be higher than the average derived in this way. As soon as lateral mixing to the width of the estuary is complete, however, the average distribution of the pollutant should correspond closely to the distribution of salt.

A prediction of the distribution of a conservative pollutant in the Severn River was derived by Stommel (1953) and a different approach was used for the Raritan River and Bay by Ketchum (1955). The results of the latter are shown in Figure 1. The fractions of fresh water and of sea water have been calculated from the salinity distribution and these are shown along the length of the estuary. From any outfall location the upstream distribution of pollution is proportional to the upstream distribution of salt, and the downstream distribution is proportional to the downstream distribution of fresh water.

Two important conclusions concerning the effect of the location of the outfall on the distribution of pollution can be reached. Similar conclusions were derived by Stommel (1953). The concentration of pollutants upstream from the outfall location is decreased by a downstream displacement of the outfall. The concentration of pollutants downstream from the

outfall is independent of the location within the estuary. Thus in an estuary the river end can always be improved by moving the outfall location seaward. Such a relocation, however, provides no improvement in the seaward direction, since the average concentration seaward remains the same.

The expected distribution of a time variable pollutant was also derived both by Stommel and Ketchum. Coliform bacteria, which decrease by mortality as well as by dilution, and dissolved oxygen which decreases by biological respiration and is augmented by solution through the surface are examples of time variable pollutants. A pollutant which decreases with time by a process other than dilution has a lower concentration at the outfall than would be found for a conservative pollutant. The downstream distribution of the time variable pollutant is decreased by an upstream displacement of the outfall. This is in contrast to the conservative pollutant, the concentration of which remains the same below the outfall regardless of its position in the estuary.

SEA DISPOSAL

From the above treatment it is apparent that the most effective place for the disposal of waste is outside the confines of the estuary entirely. In a practical sense the cost of construction of outfalls to a location well offshore is frequently prohibitive. Barging waste materials for disposal at sea, however, is a common practice, and one which may well be expected to increase in the future.

The problems in evaluating the distribution of a pollutant from the materials barged to sea differs from the estuary problem in several regards. First, as a result of the operation there is an intermittent introduction of waste rather than a continuous rate of discharge. This produces high concentrations in the disposal area at the time of discharge which gradually decrease by turbulent mixing until the next discharge takes place. Thus a steady state distribution of the pollutant is never attained in the disposal area. Secondly, the effect of river flow is much less pronounced in the coastal waters and the problem can no longer be treated in a two dimensional sense as has been used for the estuary. Furthermore, in an offshore area, the tidal currents are rotary rather than oscillating as they are in an estuary so that it is

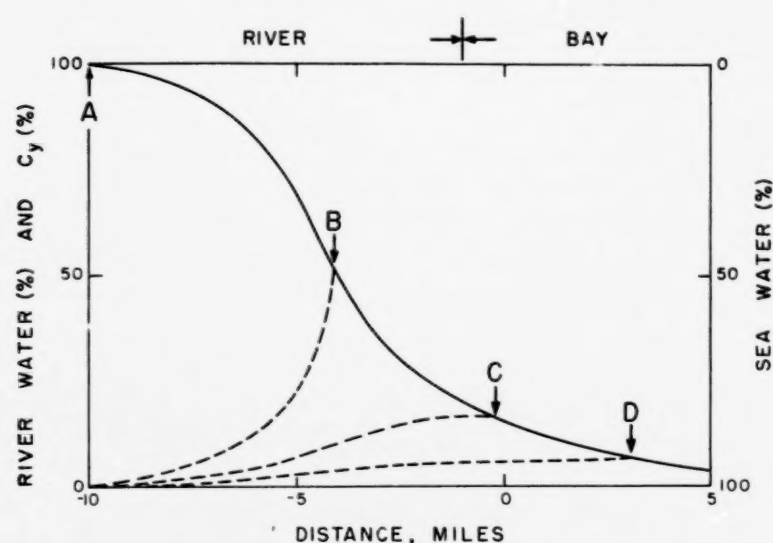


Figure 1. The distribution of fresh and salt water in an estuary and the predicted relative distribution (C_y) of a conservative pollutant introduced at a uniform rate from outfalls located at four distances along the estuary (Ketchum, 1955).

difficult to evaluate the net drift of a given off-shore body of water.

Some years ago we undertook a study of the disposal of an industrial waste at sea in the New York Bight. Two parts of this study are of general interest here. First, the distribution and dispersal of the waste immediately behind the disposal barge and second the long term accumulation within the area, which, of course, is dependent upon the rate of circulation.

The location of the disposal area is shown in Figure 2 which also presents some data on the return of drift bottles. Relatively high percentages of return were obtained near shore, particularly along the Long Island coast. The percentage returns decreased rapidly offshore, and the disposal location is in the area closest to the river mouth where none of the drift bottles return to the nearby coast.

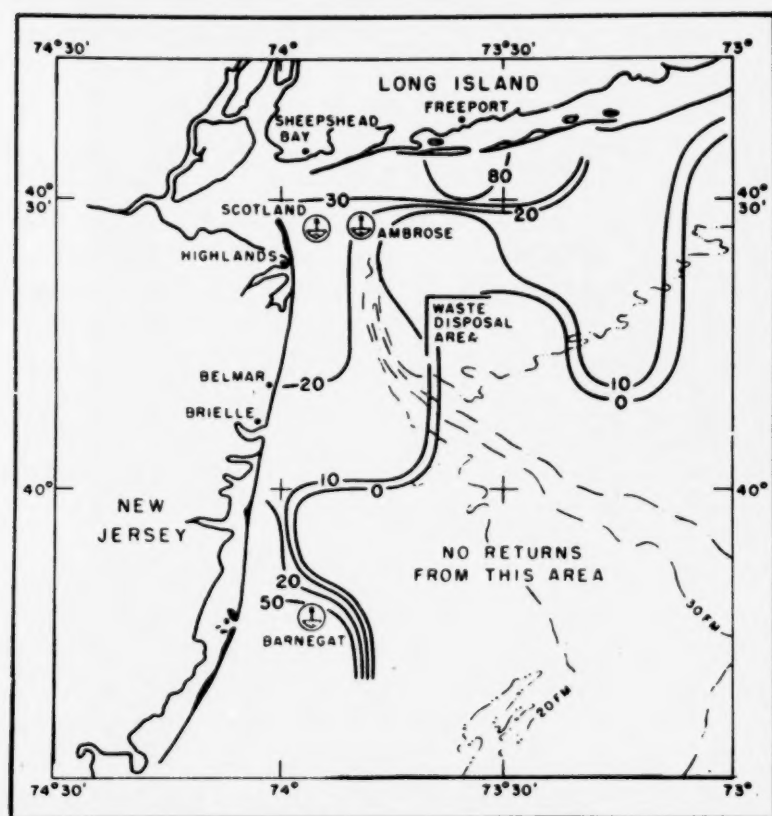


Figure 2. The New York Bight showing the location of an industrial waste disposal area and contours of the percentage return of drift bottles to the coasts of Long Island and New Jersey (Redfield and Walford, 1951).

The waste material involved was a solution of ferrous sulfate in 10% sulfuric acid. The barge was towed along a straight course at sea

while the waste was being discharged so that the wake behind the barge received equal quantities per unit distance. Because of the natural diffusion processes of the sea the concentrations decreased progressively. The turbulence in the wake, however, is not only the natural turbulence of the sea but includes the turbulence induced because of the passage of the barge itself. The latter is very erratic and produces a very patchy distribution of the waste, making analysis and evaluation difficult.

The change in surface pH of the water is shown in Figure 3 (Redfield and Walford, 1951). Immediately behind the barge the water became very acid, but this acidity was reduced not only by the mixing processes but also because of the excess base in the water which neutralizes the acidity. Within three minutes the water had returned to a neutral reaction, but patches of water slightly more acid than sea water were found even 25 minutes after discharge.

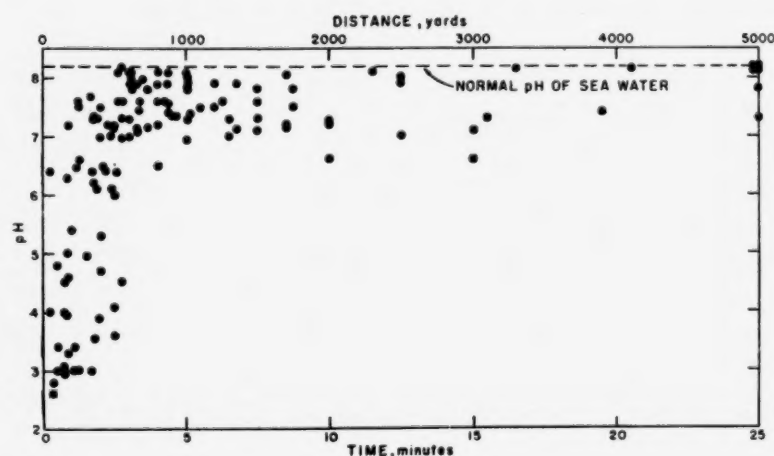


Figure 3. The surface distribution of pH in the wake of a barge discharging a waste containing ferrous sulphate and sulphuric acid (Redfield and Walford, 1951).

The distribution with depth of pH and of iron are shown in Figure 4. High local concentrations were found initially which decreased and gradually approached those of the normal sea water in the area. This gradual dilution, of course, proceeds continuously and decreases in iron concentration were observed for a period of eight hours (Figure 5). For contrast, the concentrations which were observed at various localities within the area but at some distance from the disposal area are shown by the bar graph in the lower part of this figure. Within about half an hour the concentration in the wake

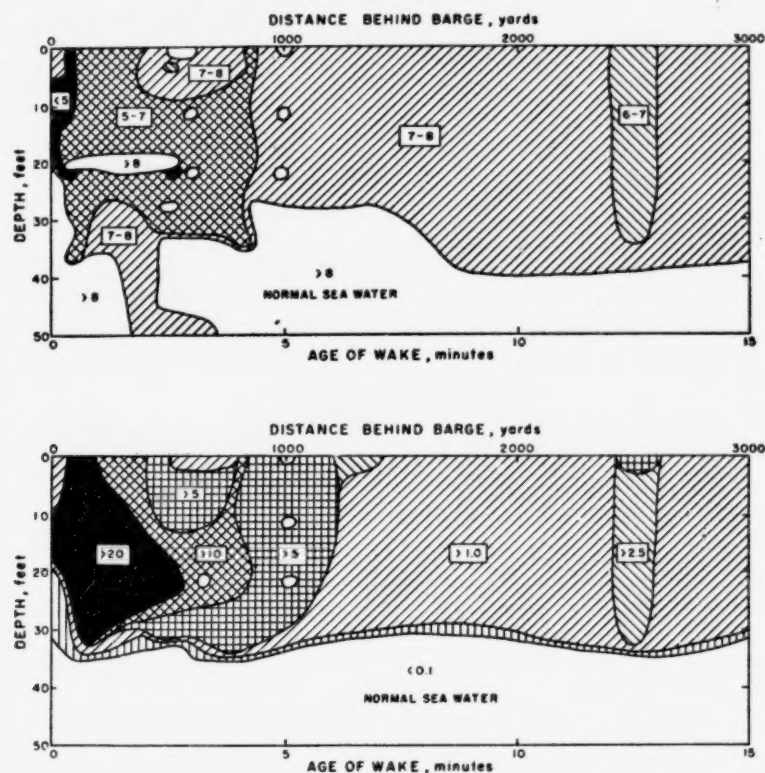


Figure 4. The vertical distribution of iron (lower) and pH (upper) graph in the wake of the barge (Redfield and Walford, 1951).

was comparable to that observed in steady state in Raritan Bay; within about four hours the concentration was comparable to that at Sandy Hook; and within about seven hours it was comparable to that observed at Ambrose Lightship. Even after eight hours the concentration had not decreased to the amounts observed in normal unpolluted sea water.

The actual concentration in the wake of the barge depends upon the rate of addition along the length of barge travel and upon the rate of turbulent mixing in the area. Ketchum and Ford (1952) developed a prediction of the fraction of the initial concentration to be expected for a variety of mixing coefficients (Figure 6). These fractions, when multiplied by the rate of discharge for a unit length of barge travel (g/cm) give the quantity (g/cm^2) to be expected in a column in the axis of the wake.

The appropriate coefficient of turbulent mixing is shown on each curve. The larger the mixing coefficient the more dilute the waste after a given period of time. This prediction was based upon the assumption of a normal distribution at right angles to the axis of the wake, though the data available at the time were not adequate to establish such a distribution. Hood

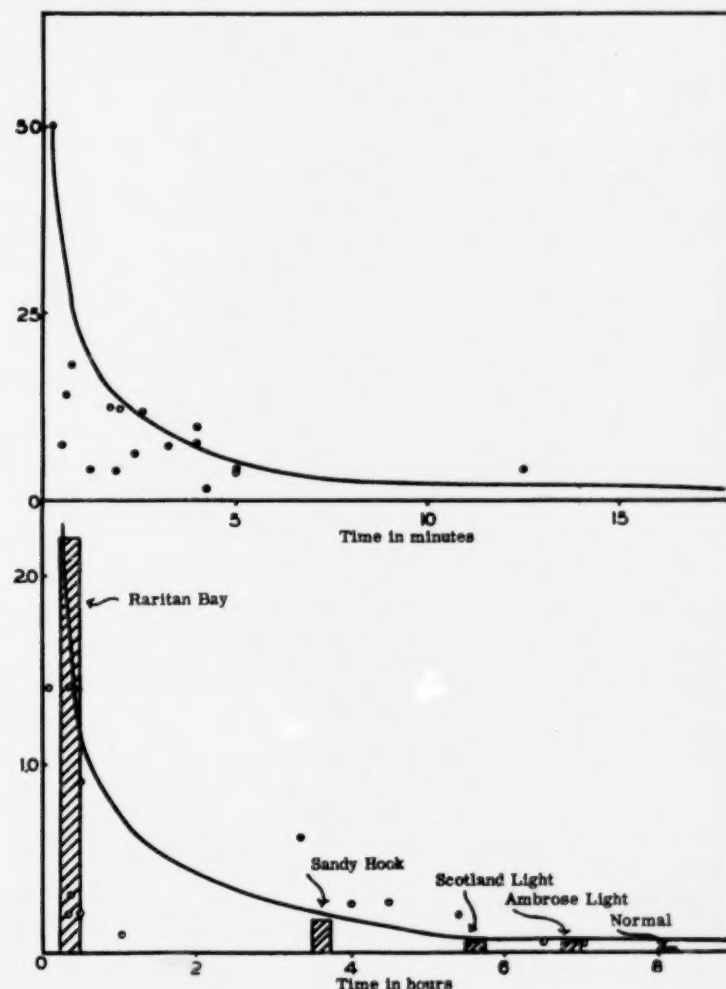


Figure 5. The surface concentration of iron in the wake of the barge at various times (upper portion). Local concentrations in various parts of the New York Bight at some distance from the disposal area are shown by the bars in the lower figure.

et al (1958) have shown that the distribution in a carefully laid wake of fluorescein dye does indeed approximate such a distribution (Figure 7).

The accumulation of iron with time as a result of disposal operations was also studied over the interval February 1948 to January 1950. Over this interval, as shown in Table 1, there appeared to be an accumulation of about three times as much iron at the end as was found at the beginning. However, observations were again made in the summer of 1958 and the concentrations now found in the area are not substantially different from those which were observed in 1950 with two exceptions. Immediately over the disposal area a recent discharge was sampled which gave higher values there than were observed in 1950 observations. As shown above such a high value would decrease

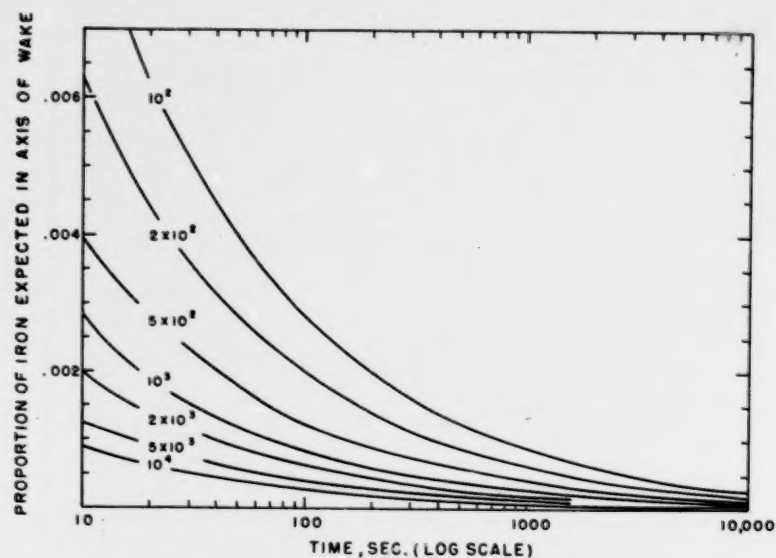


Figure 6. Prediction of the proportion of the waste in the wake after various times for various degrees of turbulence, given as mixing coefficients (cm^2/sec) on each curve (Ketchum and Ford, 1952).

rapidly and approach conditions in the surrounding water. Immediately off the mouth of the Hudson River the iron concentrations were considerably higher in 1958 than those found previously. Presumably this means that the river itself is contributing more iron to the area than it was ten years ago. Unfortunately not enough observations were made in 1958 to permit calculation of the total accumulation to compare with the data in Table 1.

Some studies of the effects of this waste disposal at sea on the biology of the area have been conducted. Since the waste is essentially nontoxic one does not observe mortality of the organisms there. The turbidity of the water, however, in the disposal area has increased so that the total photosynthesis of phytoplankton is decreased. The high acidity of the wake imme-

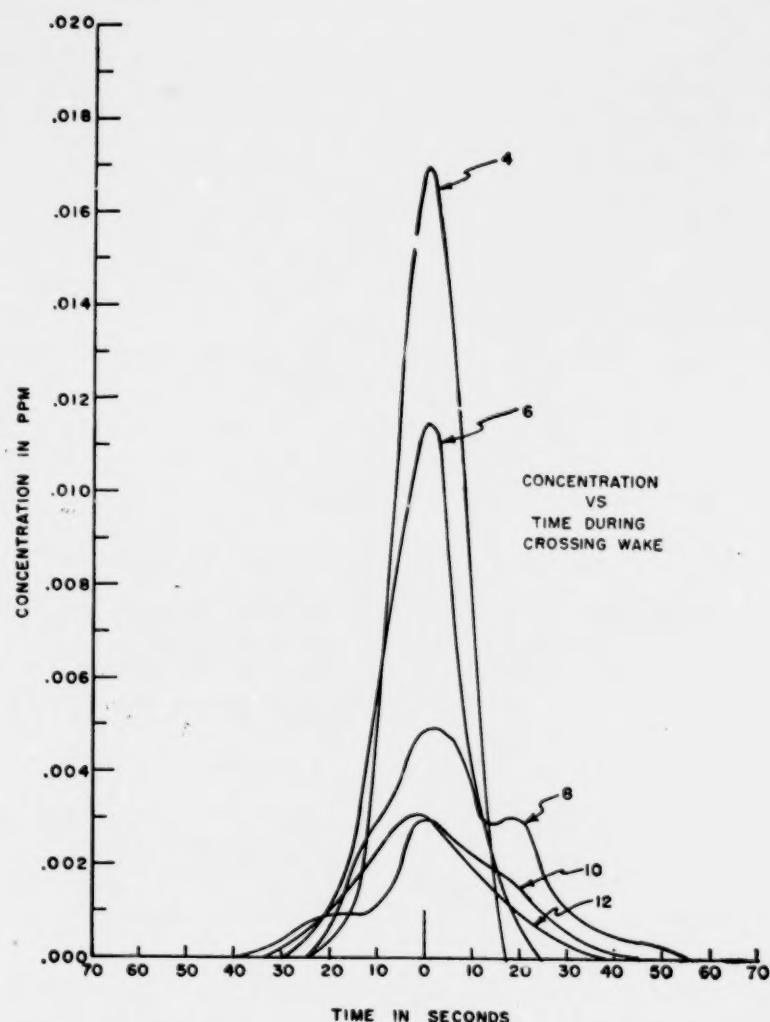


Figure 7. The concentration envelope of fluorescein observed in various crossings of a wake (Hood et al, 1958).

diately behind the barge was found to stun and immobilize the zooplankton. They recovered, however, on dilution with unpolluted water--a process which has been shown to occur rapidly in the wake. Westman (1958) has described a concentration of bluefish on the boundaries of the disposal area which has, during the past ten years, developed a fishery which did not previously exist.

Table 1. Comparison of Iron Entering New York Bight Area and Total Accumulation Within Area

Date	Surface area sq. miles	Iron contributions		Iron Accumulated tons	Time to Flush	
		River flow tons/day	Dumped at Sea tons/day		Iron days	Fr. water days
February, 1948	483	52.5	--	552	10.5	6.0
April, 1948	662	112.0	--	896	8.0	7.4
July, 1948	683	51.0	60	1,350	12.2	9.7
October, 1948	476	57.5	60	1,436	12.2	10.6
August, 1949	628	15.0	80	1,107	11.7	7.9
January, 1950	650	49.5	80	1,807	13.9	6.3

CONCLUSIONS

The direct introduction of pollutants into coastal water outside the limits of estuaries offers the advantages of maximum potential dilution and minimal return to the estuary. Increased sea disposal seems one inevitable result of the popular demand for the recovery of recreation facilities and natural resources within the estuaries. The potentially serious problems of the disposal of low level radioactive wastes from atomic power plants demands careful studies to determine the capacity of coastal sea water for such waste disposal.

The evaluation will encompass many problems, some of a local character and some of general application. Locally the problems include the protection of bathing beaches and of established fishing grounds. Local studies of the circulation and exchange of water will always be required. Each waste must be evaluated separately for its effects on the biological populations, and marine bioassay techniques will need to be developed for this purpose. Industrial

wastes particularly may react with the sea water and make conclusions based on fresh water studies completely erroneous.

The more general problems include the need to understand the ecological cycle of the sea in detail. What factors control the basic productivity or photosynthetic potential of marine waters? How is the organic matter and energy transferred along the food chain or web to those marine organisms of value to man? How are elements which are accumulated by marine organisms transferred along the food chain? The latter problem is particularly important for evaluation of radioisotope disposal (Ketchum, 1957, Ketchum and Bowen, 1958).

All in all, these are fascinating and challenging problems. The answers are needed today and will be more in demand in the future. Here indeed is a field where the public health officer, the engineer, the marine biologist and the oceanographer must work together and appreciate each other's problems before any solution can be expected.

REFERENCES

- Hood, D.W., B. Stevenson and L.M. Jeffrey. 1958. Deep sea disposal of industrial wastes. *Indust. & Engineering Chem.*, 50: 885-888.
- Ketchum, B.H. 1955. Distribution of coliform bacteria and other pollutants in tidal estuaries. *Sewage & Indust. Wastes*, 27(11): 1288-1296.
- Ketchum, B.H. 1957. The effects of the ecological system on the transport of elements in the sea. Pub. No. 551, NAS-NRC: 52-59.
- Ketchum, B.H. and V.T. Bowen. 1958. Biological factors determining the distribution of radioisotopes in the sea. *Proc. 2nd Internat. Conf. on Peaceful Uses of Atomic Energy* (Geneva). UN 402-OIC-724.
- Ketchum, B.H. and W.L. Ford. 1952. Rate of dispersion in the wake of a barge at sea. *Trans. Amer. Geophys. Union*, 33(5): 680-684.
- Redfield, A.C. and L.A. Walford. 1951. A study of the disposal of chemical waste at sea. Report of the Committee for Investigation of Waste Disposal. Nat. Res. Council, Publ. 201: 49 pp.
- Stommel, Henry. 1953. Computation of pollution in a vertically mixed estuary. *Sewage & Industrial Wastes*, 25(9): 1065-1071.
- Westman, J.R. 1958. A study of the newly created "acid grounds" and certain other fishery areas of the New York Bight. 55 pp. Unpublished manuscript.

PANEL SUMMARY

Thurlow C. Nelson, Biologist, New Jersey Division of Shell Fisheries,
Cape May Courthouse, New Jersey

As the ocean is the area of ultimate disposal of all pollution it is imperative that we learn as much as possible regarding the fate of pollutants in salt water and of their immediate and long time effects upon the flora and fauna of coastal areas. Increasing pressure upon industry for higher and more expensive treatment of their effluents is driving some to new locations closer to the sea, at the same time that greater numbers of people are coming to these shores for recreation, thus adding their wastes to the overall load which these waters must carry. One summer resort in Cape May County, N.J., shows a summer population in excess of fourteen times the year round residents. It has just opened a new million dollar disposal plant.

In British Columbia where ten percent of its resources come from the sea, nine pulp mills are drawing upon lush nearby forests to harvest much of the area's principal wealth. Here we see the conflict in sharp focus: mills located on the chief salmon streams are creating at each sewer outfall a barrier to upstream migration of spawning adults and a dangerous hazard to passage of young fish back to the sea. Ultimate disposal of waste liquors at sea is prolonged through sharp stratification, with lower salinity waters above the pycnocline carrying wastes with very little admixture with underlying saltier and colder waters. Additional hazard results from compensatory upstream movement of lower, heavier water carrying pollution upstream.

Spent liquors from Kraft process plants are evaporated to lower volume and sprayed as fuel into furnaces with recovery of chemicals, but sulfite liquor is discharge into the tidal ebb and flow. This liquor contains dissolved and suspended materials. Hexose and pentose sugars form 15 percent of the dissolved materials, while fern pulp accounts for much of the suspended

materials. When deposited in sludge banks pulp is but slowly transformed. Transparency of the water is reduced from 25 to a minimum of 5 feet. Long term effects are shown by sterile surface water and no fouling organisms where in 1927 normal chemical conditions and usual estuarine biota were present.

Many biological problems appear in the application of bioassays in an attempt to evaluate the effects of industrial wastes. Oregon, with its pulp mills employing both sulfite and Kraft processes as in Canada, experiences difficulty in the demonstration of sulfite liquor in coastal waters. Laboratory tests, however, reveal marked reduction in numbers of oyster spat produced from larval cultures in sulfite liquor in excess of 100 p.p.m. In sharp contrast, however, 50 p.p.m. gave much better results than controls. In the absence of any liquor, larvae of Ostrea lurida failed to complete metamorphosis, while with 50 ppm. good spat survival was attained. One probable explanation lies in the long experience of Dr. Loosanoff and associates at the Milford, Conn., Marine Laboratory of the F.U.S.W.S. Here have been demonstrated lethal effects of fungi and bacteria upon unprotected cultures; hence it is possible that 50 ppm. of sulfite liquor while not harmful to the larvae may protect them from fungi or bacteria which destroyed the controls.

The California Coast receives in excess of a billion gallons of sewage daily, most of this concentrated in the southern portion of the State. With little or no river discharge in summer together with wide use of sea water in many industrial processes, need for purity of these waters is further enhanced by great influx of tourists who use the ocean beaches for bathing, fishing and gathering of shellfish. Of considerable interest is the demonstration that E. coli is not a normal inhabitant of sea water, but resistant forms have been found 5 to 10 miles from the nearest sewer outfall. Estimated dis-

charge of *E. coli* from the California Coast daily is 2×10^{18} . These if evenly distributed over the continental shelf would give 50 per ml. That this does not occur is due to: dilution, flocculation, aggregation, sedimentation, adsorption, predation, antagonism, antibiosis, bacteriophage, sunlight, and other adverse factors not present in a test tube. Time required for 90 percent reduction near outfalls ranges on an average from 3 to 8 hours. Increase of bacteria in offshore waters may be explained by their capture in surface films. Small amounts of sewage may be beneficial, but excessive amounts cause serious disruption of food chains, fin and shell fish, and sea weeds. It is most encouraging to find numerous comprehensive research projects now under way.

Application of formulas for flushing of tidal estuaries developed by Ketchum, Stommel and others of the Woods Hole Oceanographic Institution to Biscayne Bay, Florida yields interesting agreements. Bay volumes were estimated only for areas where most intense flushing occurred. Many areas are shallow and indented and have relatively little water movement. Incomplete mixing occurs to approximately one-half the depth of 15 feet. Flushing time is 7 to 9 days.

The zooplankton population is much smaller than Ketchum found in Raritan Bay; predation is negligible. The predicted M. P. N. value was 4 times that actually observed as compared with 3 to 7 times the observed M. P. N. found by Ketchum for Raritan Bay.

Although less heavily polluted than either the northeastern Atlantic or southern California coasts the Gulf area has supplied the most comprehensive effort by industry to date to determine actual damage to marine life from industrial effluents. Supported by large contributions from major oil companies engaged in offshore and marshland drilling operations, Project 9 of Texas A. & M. Research Foundation carried to completion studies of the effects of oil and bleedwater upon oysters in Louisiana waters. Ten percent bleedwater will adversely affect pumping rates of oysters but effects of large dilution of this by product from oil wells is demonstrated by numerous large and rapidly growing oysters attached to wells and adjoining structures. Oil in heavy concentration in laboratory studies will kill oysters, *Crassostrea virginica*. However, in amounts escaping from wells or mixed in drilling muds the effects are limited to oily

tastes imparted to shellfish. Damages resulting from this have been settled out of court, and in at least one instance tainted oysters subsequently lost their oily flavors and were marketed.

A major value from Project 9 was the placing of oysters pathology on a sound foundation through demonstration of heavy natural mortality of this mollusc from disease and from predators, first among the former being the lowly fungus *Dermocystidium marinum*. Mobile Bay and Mississippi Sound waters are clean. Texas with very limited flow of fresh water into the Gulf has few problems of pollution. Galveston Bay is the most heavily polluted, but some of the best oyster reefs in the Gulf lie in the lower Bay. Records reveal that 38 percent of fishing in Texas is concentrated in Galveston Bay with 36.5 percent of total fish caught here.

Pollution of the lower Raritan River and Raritan Bay, New Jersey, by large volumes of 10 percent sulfuric acid and iron sulfate reduced these areas to a biological desert. After careful study of the project by the Woods Hole Oceanographic Institution a large scow, the Sayreville, was constructed in which these wastes are towed twice weekly to the open sea off the New Jersey coast. Here are met conditions very different from those found in polluted rivers. Pollution is intermittent with high concentrations released during short periods. Tidal currents being rotary, the mass of pollution introduced slowly reaches ultimate dispersal. Samples collected in the wake of the Sayreville show that the sea water returns to neutral within three minutes, but is less alkaline than normal sea water even up to 25 minutes. Ultimate recovery to normal alkalinity is not reached after 8 hours. The Hudson River brings down appreciable iron which while non-toxic lowers photosynthetic activity through increased turbidity. Evidence recently obtained indicates an increased fishery for blue fish in the area of disposal. Increased transport to sea of objectionable effluents and sewage sludge appears inevitable. It is reported that even now the U. S. Steel Plant at Morristown, Pa., on the Delaware River is exploring such disposition of acid pickle waste.

Marine pollution problems include the protection of bathing beaches and of established fishing grounds. Local studies of the circulation and exchange of water will always be required. Each waste must be evaluated separately for its

effects on the biological populations, and marine bioassay techniques will need to be developed for this purpose. Industrial wastes particularly may react with the sea water and make conclusions based on fresh water studies completely erroneous.

The more general problems include the need to understand the ecological cycle of the sea in detail. What factors control the basic productivity or photosynthetic potential of marine waters? How is the organic matter and energy transferred along the food chain or web to those marine organisms of value to man? How are elements which are accumulated by marine organisms transferred along the food chain? The latter problem is particularly important for evaluation of radio isotope disposal (Ketchum, 1957, Ketchum and Bowen, 1958).

All in all, these are fascinating and challenging problems. The answers are needed today and will be more in demand in the future. Here indeed is a field where the public health officer, the engineer, the marine biologist and the oceanographer must work together and appreciate each other's problems before any solution can be expected.

Owing to substantial knowledge of ecological and physiological activities, and requirements of the American oyster, *Crassostrea virginica*, now the best known marine animal scientifically in the world, it is a valuable indicator of adverse biological conditions in coastal waters. Of first importance, however, is to differentiate effects of natural agents of destruction from those for which men's activities are responsible. Study of upper Cretaceous deposits in New Jersey, estimated to be sixty million years old, reveal great numbers of fossil oysters. *Exogyra* and *Gryphaea*, largest oysters the world has produced. These molluscs did not form reefs raised above the bottom, but each oyster lying singly with its deeply cupped left valve downward became a mud trap when greatly increased coastal turbidities followed rapid elevation of the Appalachian mountains. Study of shells and deposits in which they lie yields strong evidence of extinction through burial in accumulated silt.

An ancient Indian fish weir estimated to be 5000 years old uncovered 40 feet below the sur-

face in the Back Bay region of Boston, Mass., revealed great numbers of oyster shells increasing at higher levels until suddenly terminated. Influx of sand together with species of marine diatoms and molluscs indicate the destruction of the outer barrier beach exposing the area to the open sea, resulting in higher salinities, lower temperatures, influx of marine enemies of the oyster, together with wholesale burial of living oysters in marine deposits. While natural agencies still cause major disasters to the industry as in destruction of more than a million dollars' worth of seed oysters off New Haven Harbor in the November 25, 1950, hurricane, pollution by copper wastes destroyed the thriving oyster industry in Raritan Bay between 1912-1917.

Failure to halt southward migration of littoral drift into Barnegat Inlet combined with faulty placing of jetties resulted in stagnation of waters in Barnegat Bay. A heavy oyster set of considerable value died in 1925, followed by abandonment of the entire seed producing area of 2400 acres. During the prior century this area contained the most productive natural oyster reef north of Chesapeake Bay.

Delaware Bay, home of an oyster industry producing an average of 14 million pounds of oyster meats annually, one seventh of the entire United States, has suffered losses from shifting of unstable bottoms during storms, burial by mudworms, *Polydora ligni*, gill injury by oyster grab, *Pinnotheres ostreum*, plus constant heavy inroads by natural enemies. Succession of four years of low rainfall, two the driest of record starting in 1929, raised salinities permitting the invasion of natural seed beds by oyster drills with reduction of the oyster harvests by one half. In 1957-58 epidemic disease associated with bacteria and lowly fungus-like organism destroyed more than three million dollars worth of oysters.

The Second Delaware Diversion Case in the U. S. Supreme Court 1952-53, settled by stipulation, grants New York City an increased diversion from 440 million gallons daily to 800 m.g.d. from the headwaters of the Delaware River. New Jersey and Pennsylvania receive a guaranteed minimum flow at Trenton of 3400 cubic feet per second from storage reservoirs

in New York State, thus protecting industries on the lower River from salt intrusion. This compromise for greatest good to the greatest number will still further increase hazards of oyster production in Delaware Bay. Chief concern is felt over reduction of some chlorophyll assays

in waters on oyster grounds to one tenth those of former years, raising the question as to possible effects of herbicides and other destructive materials destroying both algae and bacteria. Low bacterial counts therefore may not be a true measure of purity of our waters.

AN ADMINISTRATOR LOOKS AT THE POLLUTION PROBLEM

Banquet address by Seth Gordon - Member of the President's Water Pollution Control Advisory Board and former Director of the California Department of Fish & Game

By way of introduction, permit me to tell you that I have worked on the various problems involved in the conservation of natural resources for over 45 years. Only about 28 of them were actually in the capacity of a top-level administrator.

The balance of those fleeting years were mostly devoted to heading up civilian conservation organization activities from one end of the country to the other, or doing consulting work.

Due to some recent countrywide upsets in the political arena, I have again become a free-lance worker. As such, I can speak candidly to you scientific workers.

Speaking of freedom of speech, since I relinquished my administrative position in California on April 1, I have been hearing heretofore inaudible voices. However, I have not yet experienced the same dismay as did the old chap who was finally persuaded to wear a hearing device. His friend who sold him the idea about a week later inquired: "Well, Bill, how do you like it?" The old fellow replied: "Oh, boy, am I having myself a ball! I've changed my will twice in three days!"

VIEWS ON POLLUTION VARY

The "pollution problem" means different things to different people. To some, it means an interference with their freedoms of bygone years to dump their wastes into their neighbors' front yards and hope they will tolerate it. To others, it means paying the cost of disposing of them properly -- less than a cent a day per person for domestic wastes, and comparatively few dollars for industrial wastes. Others are concerned with the taste, the potability, or the safety of the water they draw from the tap for domestic use. Still others are concerned be-

cause pollution interferes with their modern-day manufacturing processes, the irrigation of crops, the destruction of fishlife, swimming, boating, and other recreational uses. And to others, pollution means the destruction of esthetic values which they want restored to a once again suitable condition for human enjoyment.

"POLLUTION" MEANS HEADACHES

To the administrator, whether he be the purveyor of water to the public or one charged with the administration of laws seeking the elimination of pollution, it means something else again -- mostly headaches -- because regardless of the direction in which he moves he will make somebody unhappy.

Speaking of esthetic values reminds me of an unforgettable experience I had in northern Illinois during the month of August, 1926. One of my friends, who was involved in the development and administration of recreational facilities along the DesPlanes River, invited me to join him for a Sunday afternoon inspection to see thousands of people from the congested areas of that big metropolis enjoying the publicly provided opportunities for swimming, picnicking, etc.

"CHLORINE OR NOTHING?"

Near the end of the trip we came to an impoundment on the upper reaches of that river, and there were hundreds of swimmers, young and old, cavorting about in what was instantly recognizable as badly polluted water, both industrial and human wastes. Upon expressing utter astonishment that a public agency would encourage humans to use filthy water for such purposes, he blandly replied: "Oh, it's perfectly safe. We dumped over 600 pounds of chlorine into that dam on Friday. And, more-

over, the public beaches on the lakefront are badly overcrowded, so it's this or nothing."

My further comments lost me a new-found friend.

But enough of such personal experiences. There have been many more, equally bad.

FIRST SURVEY BY I. W. L. A.

As the conservation director of the Izaak Walton League of America, it was my privilege to aid in the collection of the first nationwide survey to determine the extent to which inland waters were polluted, a task assigned to the League by the National Conference on Outdoor Recreation. I'm sure you'll not be startled to hear that of the waters surveyed 85% were polluted to a considerable degree, and the percentage with high pollution was appalling. That was the beginning of the League's organized frontal attack on pollution, which finally led to federal legislation (in the 80th Congress) imposing certain duties upon the Surgeon General theretofore studiously avoided, except where disease epidemics were involved. Next came the Federal Construction Grants Program under P. L. 660, 84th Congress. More of that later.

I need not remind you who are assembled here for this Seminar on Biological Problems in Water Pollution that a considerable portion of the fine work being done here at the Robert A. Taft Sanitary Engineering Center also has its roots in that legislation.

WHAT POLLUTION MEANS TO CIVILIZATION

In recent months there have been many outstanding public addresses on water, and what it means to our future well-being as a Nation. One of the best of these was by Congressman W. R. Hull, Jr., of Missouri to the convention of the National Wildlife Federation, New York City, February 28, 1959. Among other things Congressman Hull said:

"One of the reasons why the underdeveloped countries of the world today are underdeveloped is because of the inadequacy of their sanitary water supplies. The effects of polluted waters are a tremendous obstacle to raising the living standards in those countries.

"The hard lessons learned by other nations should not be lost upon us here in the United States. *** As the result of accumulated misuse of our water resources and the impact of industrial and technological advances upon our water supply, we are today faced with a monumental water pollution problem. It is a problem which, if not attacked aggressively today, will overwhelm us tomorrow."

ACTION CAME LATE

The Congressman then reminded his audience that action by the Federal Government to deal with stream pollution and its pernicious effects was taken only eleven short years ago; and that "Polluted water can kill people and it can kill industry *** By curbing pollution communities attract new residents and industries. By not fighting the problem, communities wither and dry up."

No doubt you will all recall the rather startling article in The American Legion Magazine last year. It made a lot of people shudder! After discussing Wheeling's (West Virginia) inability to purify the Ohio River water so that their people would accept it, there was this pungent paragraph:

"When our tap water becomes so rank that it affects the flavor of our coffee and our beer, then we shall have a home demonstration of the social crime of pollution. *** We will never begin to restore our inland and coastal waters -- to experience again the healthful activities and delights of sparkling streams and clean, spring-fed lakes -- until we arouse public opinion."

Actually, my friends, in the foregoing quotes we have the key to our problem. Why have the American people been so progressive in many fields, yet so deplorably slow to become fully aware of the deadly impacts of water pollution? Surely it isn't because you technical workers have fallen down on the job. Or have you?

PUBLIC VIEWS ARE NARROW

As an administrator, I fear that we have used the term "conservation of our natural resources" far too loosely. And I fear further that since the conservation organizations are the ones who have long carried the burden of the battle to

educate the public concerning pollution, there has been a tendency for the public to look upon such campaigns as representing only the views of "a bunch of crazy fishermen who merely want better fishing."

Perhaps the definition of conservation that most closely fits my own philosophy is: "the use or management of the natural resources for the greatest good for the greatest number for the longest time."

CONSERVATIONISTS IN MINORITY

Conservation is a popular concept like "democracy and freedom." Everybody believes; everybody is for it. But in my opinion the true conservationists, those who understand the needs for sound management of natural resources, and are willing to forego immediate personal gain in the interests of our very survival and our future, are unfortunately still far too much in the minority.

Those of us who deal in water, or manage resources which are completely dependent upon water, face an enormous challenge. We must find the means and the courage to meet that challenge squarely and solve it before it becomes a catastrophe.

Without an aroused public opinion, we can't hope to get better laws to deal with pollution. And without better laws, and funds to administer them properly, in most of the states we are merely fighting a delaying action.

NEED BECOMING CRITICAL

We can no longer afford the philosophy of progressive degradation of the quality of our public waters from their headwaters to the sea. Today the need for clean, pure water is becoming critical along the entire course of our watersheds for cities, industries, agriculture, and recreation.

Even California's ocean waters, once thought to have an unlimited capacity for waste assimilation, (and I know this applies to other coastal states) are showing serious signs of degradation due to pollution. The commercial and recreational fishing potentials of many of our bays and shallow coastal areas have been reduced to the

point where they are no longer capable of supporting these increasingly vital activities.

We must no longer permit the virtual writing off of public waters for the sole purpose of waste disposal at the expense of many other legitimate beneficial water uses. The practice of condoning and justifying extensive waste dilution zones on the basis of "economic expediency" is simply not in keeping with modern day reality.

Fortunately, many Californians are beginning to feel that waste disposal into public waters must be considered a privilege, not a right, and as such the discharger should no longer receive nor expect to gain economic advantages at the expense of the public welfare.

CALIFORNIA PROBLEMS CITED

Speaking of our California problems, you might be interested to know that during the past two years five state Departments have waged an unceasing campaign, with the Department of Fish and Game unfortunately having to carry a large share of the brunt of it through its publications and other media, to get our pollution laws materially strengthened. The directors of the five Departments (Health, Agriculture, Water Resources, Natural Resources, and Fish and Game) sit as ex officio members of our State Water Pollution Control Board. They spent much time in evaluating the situation, and came up with a set of recommendations to a legislative committee that held extensive hearings throughout the State.

In their joint statement the five agencies declared:

"There is a serious need for a clearly defined statement of basic state policy regarding pollution control. It is imperative this policy be formulated now by the Legislature and be incorporated in the water pollution laws."

And for the benefit of those of you present who are involved in maintaining proper biological conditions in our public waters for fishlife, the statement said:

"Mere prevention of toxic conditions is not enough to protect fish and wildlife.

Emphasis should be placed on maintaining suitable habitat and food supply (and that) ample margins of safety should be established so that any errors will be on the safe side."

PROGRESS IN THE BALANCE

The Interim Committee on March 11, introduced its recommended bill, A. B. 1974, which included substantially the recommendations of the five departments in toto. What progress it makes remains to be seen, but we believe the prospects are very good, despite strong opposition from various quarters.

Now a further word about our attitude on "mere prevention of toxic conditions." In the past far too much emphasis has been placed upon "fish kills" to determine whether polluters should be prosecuted, or have remedial steps forced upon them. Instead of approaching the matter from the standpoint of how much poison the fish can take before they are killed, we should approach it on the theory that we should keep our waters fit for fish and other life to thrive. In other words, let's stop talking about killing fish. Let us put our emphasis on enhancement rather than have laboratory workers constantly trying to determine how much poison can be dumped in without being lethal. The people at Taft are well aware of this, but it is an area in which you visiting technicians can be tremendously helpful to the administrators. Without the guidelines from you we are helpless.

MORE RESEARCH NEEDED

We mentioned earlier the conditions along our coasts. If there is one field in which much more pollution research is needed it is our estuarine waters. We are making a start in our bays and along the coast of California, but we need much more research to give us the facts with which to bring about remedial actions. I trust the Robert A. Taft Sanitary Engineering

Center may find it possible to devote much more attention to this important field. It is still wide open.

I should like to comment briefly about the status of the Federal Construction Grants Program. This is by far the biggest boost the states have yet received in their efforts to eliminate pollution. It has stepped up the construction of treatment works by municipalities all over the land. Every dollar of Federal aid has been matched by more than four dollars of local money. Instead of cutting back the program, we should double it! All this recent talk about shifting such responsibility back to the states is foolhardy, to say the least. We certainly can't afford to lose our hard-won gains, piece by piece.

FEDERAL GRANTS HELP

As one of my boys recently put it, "The Federal Grant Program has been a 'shining light' in our pollution control problems. Without it California would be in a very serious position in relation to pollution." And I dare say the same thing is true of every state represented in this fine gathering of specialists. So let's go forward, not backward!

If you want to help us administrators, give us the information, the tools, the technical guidelines, we need to proceed from here. And, above all else, give us basic information in such a form that can be relayed to the general public, so that our people can be properly impressed with the dire need for cleaning up a mess far too long shunned by everybody.

As another example of how an administrator looks at the pollution problem, I have brought along a new California Department of Fish and Game motion picture, which I am sure will speak for itself. It is aimed at everybody, not just the water purveyor, or the chap who wants better fishing: WATER: LET'S KEEP IT CLEAN!

RESEARCH FOR THE ESTABLISHMENT OF WATER QUALITY CRITERIA FOR AQUATIC LIFE⁽¹⁾

Clarence Cottam, Director - Welder Wildlife Foundation, Sinton, Texas, and
Clarence M. Tarzwell, Chief of Aquatic Biology - Robert A. Taft Sanitary Engineering Center
U.S. Public Health Service, Cincinnati, Ohio

INTRODUCTION

Water is a basic necessity of life. The more complex the culture of a people and the more extensive their industry, the more water they require. As population and industry increase, water requirements are rapidly approaching the limits of available supply and in a short time will exceed the supply in certain areas. Our supply of fresh water cannot yet be appreciably increased by any known economically feasible methods. In the future, except in coastal areas where sea water may be economically converted into fresh water, we can expect to extend our water resources mainly through reuse. As time goes on it will become essential for those using water to return it to the water course in a condition suitable for other beneficial uses.

The suitability of a water for a required use is a measure of pollution. Pollution may be defined as the addition of any material or any action or condition which interferes with, lessens, or destroys a beneficial use of a water. Water pollution may be abated or prevented simply by returning waste waters to a stream, reservoir, pond, lake, or ocean in such condition that they do not interfere with or destroy beneficial uses. Accomplishment of this clear cut objective is not always an easy task. Wastes and pollutants are many and varied, and treatment or purification of many is extremely complicated.

CRITERIA FOR BENEFICIAL USES

The main beneficial uses of our waters are: domestic, agricultural, aquacultural, industrial, recreational, aesthetic, navigation and power. To maintain or restore the suitability

of our waters for these stated purposes, our first task is to determine the water quality characteristics which are required for each of these uses for we cannot effectively measure pollution, determine needed correction, or evaluate control measures until we have established these essential characteristics. In this paper attention will be directed toward research needs for the establishment of water quality criteria for aquatic life. Water quality characteristics required for the production of suitable aquatic crops are determined by the environmental requirements of the plants and animals which it is desired to produce. The quality of the water must be such that it is, and will continue to be, conducive to the survival, growth, reproduction, and general well being of plants and animals. The setting of water quality criteria for aquatic life is, therefore, a problem in applied ecology. These criteria should not be based on average conditions as it is the extremes of environmental conditions which are limiting. They can be determined only through basic studies of the environmental requirements of all life history stages of the organisms to be protected or propagated, and these studies must form the basis of any efficient research program directed toward the protection of aquatic life from pollution.

Evaluation of Pollution

While determination of the water quality requirements for aquatic life must come first in a well planned program directed toward pollution abatement, several other steps also must be taken. We must develop more adequate chemical and biological methods for determining if requirements are being met. Further, we must devise procedures for use of the biota

(1) Contribution No. 36, Welder Wildlife Foundation

to indicate the severity and extent of pollution. Research also is needed for development of new and more effective methods for treatment of waste waters.

The present practice in the handling of wastes seems to be to get rid of them by what is believed to be the most effective or economical means available -- dumping into the nearest stream, burning, burying, or destroying by chemical or biochemical processes. Sorely needed are waste treatment procedures which are not simply destructive but are directed toward conversion of waste organic materials into useful products. One means of accomplishing this would be through the use of microorganisms. This field offers great possibilities as indicated by the notable progress with the various fermentation processes.

Since the qualitative and quantitative composition of the biota is determined by water quality and extremes in environmental conditions, the biota is a measure of these conditions. When the environmental requirements of various groups of the biota are known, they can be used to indicate past conditions and extremes in environmental conditions which have prevailed during their life cycles.

Research is now being carried out for the determination of the environmental requirements of certain aquatic animals. These investigations must be greatly expanded to include many more species if we are to secure data essential for the use of these organisms as indicators of environmental conditions and for the setting up of water quality criteria which will insure the protection and well being of the aquatic biota. We need to determine the environmental requirements not only of fishes but also those of the organisms in the food chain. At present there is great need for information on the environmental requirements of aquatic insects and the toxicity to them of wastes and pesticides. More research also is needed on the effects of various wastes on aquatic life under conditions of both short-time and continuous exposure. This is essential if we are to set up application factors to be used with short term bioassays to indicate concentrations of wastes which do not interfere with the general well being of the organisms.

Settleable Solids and Turbidity

Much more needs to be known of the direct and indirect effects on the aquatic biota of suspended and settleable solids; of their direct mechanical effects on fishes and other organisms; of the effects on benthic organisms of their deposition in varying amounts on stream and lake bottoms; and of the effects of turbidity on light penetration, photosynthesis, and the energy cycle. Information is needed on the environmental requirements of species and groups of algae and plankton. We should know more about the amount of light required by planktonic algae to produce as much oxygen by photosynthesis as they consume in respiration, and about the minimum amount of light required for the growth of rooted aquatics. When this information is known, turbidity standards can be established to insure the penetration of adequate light to specific depths.

Temperature

Temperature is an important factor in the aquatic environment since it influences the well being and response of fishes in a variety of ways. Temperature may be a lethal agent or it may influence migration, metabolic rate, amount of oxygen required, growth rate, activity, time of egg laying, and toxicity of various pollutants. Therefore, the present raising of stream temperatures by industrial wastes; nuclear reactor cooling waters; and by return irrigation flows becomes increasingly important. If this trend continues, summer temperatures will reach critical levels in many areas and there may even be significant changes in the winter temperatures of our streams. The latter can have both good and bad effects. It is entirely possible that this warming will induce fish in certain areas to spawn at unusual times. Weekend suspension of industrial operations with an accompanying drop in water temperature may then result in a kill of eggs and fry. Since most of our aquatic organisms in the temperate zone have evolved under seasonal temperature variations, some require low-temperature resting periods. High winter temperatures can have drastic ill effects. Additional information is needed on the maximum and minimum temperatures and the extent of fluctuations which can be tolerated for a short time by the aquatic biota. In the future it may be that in certain areas we will be as concerned with the problem of high winter temperatures as we are with high summer temperatures.

Year round studies to determine thermal requirements are needed, not only for all development stages of fishes but also for fish food organisms. Thermal criteria should provide not only for survival but also for the general well being of the important species in the aquatic biota. More study is needed to determine those organisms requiring low-temperature resting periods and possible population shifts as temperature conditions become more favorable for one group and less favorable for another. In some instances increased temperature favors the coarse species which develop at the expense of the more desirable game species.

Oxygen

Some investigations are now being made on the oxygen requirements of our important food and game fishes but a great deal more is yet to be learned. More data are needed on the oxygen requirements of eggs, fry, fingerlings, and other age groups. We need to know the most favorable levels for their development, growth, reproduction, and well being, how long they can exist at various low oxygen levels, and the minimum level at which they can exist for short periods. This information also is needed for the micro- and macro-invertebrates which are important as food. We know very little concerning the oxygen requirements of fish food organisms and other organisms in the food chain.

A large number of short-duration studies have been made on the dissolved oxygen requirements of resting fishes. However, definite information is needed on the favorable or preferred DO levels for the entire life cycle under as nearly natural conditions as possible. Seasonal differences in DO requirements for different species are significant. Data are needed not only on the minimum amount of DO that can be tolerated for varying periods and under conditions of activity but also on the optimum levels.

More detailed information is needed on the effects on oxygen requirements of various concentrations of carbon dioxide, hydrogen sulphide, methane, ammonia, and other products resulting from the decomposition of organic wastes. Additional information is needed on the direct and indirect effects of pH, temperature, and toxic material on the amount of oxygen required by the aquatic biota.

Toxicity

Although a great deal of bioassay data have been assembled on the toxicity of various materials to fishes, much of it is of limited practical value in the establishment of water quality criteria. Many of these bioassay tests were of short duration, one to a few hours. Such short-time tests do not indicate even the acute toxicity of many materials. In many instances the test conditions are not given. We need to know the species used and the characteristics of the dilution water such as temperature, DO, pH, acidity, total alkalinity, and hardness. These are of outstanding importance since they greatly influence the toxicity of many wastes. Because some toxicants are slow acting and others are accumulative, it is desirable to run bioassays for at least 4 days.

Such short term bioassays, will indicate acute toxicity and something of the accumulative effects. However, long-term continuous flow tests of 30 days or more are valuable for more adequately indicating concentrations which may be safe under continuous exposure. It is this latter information which is needed for the setting up of water quality criteria. If a bioassay of a particular waste uses for dilution, water from the receiving stream at the point at which the waste is to be discharged, it will automatically evaluate those quality characteristics which influence toxicity. If the 48- or 96-hour TL_m value secured in this way is compared to concentrations determined to be safe by continuous flow tests, a ratio or application factor can be obtained. This factor may be used with short-term bioassay results in other areas to indicate concentrations which are safe under continuous exposure, if certain other conditions are taken into consideration. These conditions include the sensitivity of different species and of different age groups of the same species, variations in temperature and in the strength of the waste and other water characteristics during the annual cycle.

While application of numerical criteria may be possible over wide areas for those materials the toxicities of which are not significantly changed by normal variations in water quality, a tailor-made approach is essential for many materials and for most complex wastes, especially for those wastes whose toxicities are determined by the character of the receiving water. However, after TL_m values are de-

terminated, application factors can be used to indicate safe concentrations for that particular area.

A great deal of research is needed for the development of these application factors. A wide range in species sensitivity to the same waste requires that toxicity tests be made for all of the important species in the population with each of the main kinds of industrial wastes. This will entail not only a great deal of work but the development of bioassay methods for many of the aquatic invertebrates. In carrying out this work, generalizations can be used only with great caution because a species resistant to one material may be sensitive to another. Since the aim is to protect all desirable species in the population, the criteria must protect the most sensitive species.

While bioassays are valuable in indicating acute toxicity and safe levels of toxic wastes in receiving streams, it is believed that other types of tests also should be used. In certain instances physiological tests may be more efficient and effective in determining safe levels and setting application factors.

Bioassays are based on "the all or none" concept. The wastes kill or they do not kill and results are based on the percentage of kill. Toxic materials in concentrations below the lethal level may drastically affect aquatic populations through decreased resistance to disease and parasites, limitation of feeding and growth, prevention of reproduction, or decreased activity. Tests for swimming ability, feeding, growth rate or metabolism or for other physiological effects may be more effective than long-term bioassays for determining concentrations not harmful to aquatic life under conditions of continuous exposure. It is firmly believed that more physiological tests should be carried out. Such tests may well serve as direct indicators of criteria for specific wastes. Physiological studies should give more understandable information on how and why toxicants act, which would be useful in the evaluation of new toxicants and in the development of treatment procedures. Physiological studies would also indicate rapidity of recovery and development of resistance to toxicants, and factors associated with these changes.

Studies of the effects of repeated exposures and of additive or accumulative effects would

be of great value. Consideration should be given to the determination of synergism and antagonism and to the cause or causes of such action when two or more materials are added to the aquatic environment. Attention must be directed to the effects not only of higher concentrations but also of continuous exposure to small concentrations especially as these may interfere with metabolic processes or retard enzyme production or oxidation in the body cells. The effects of minute quantities of toxicants can result in delayed actions which are very difficult to associate definitely with the original cause.

It is apparent that much research is needed on the development of treatment methods for the removal of toxic materials from waste waters. Continuous research is also needed to determine the toxicity of new products before they are extensively used in or near the aquatic environment.

Tainting of Fish Flesh

While materials which taint fish flesh may not be present in lethal concentrations, they can effectively destroy a fishery. If only a few fish are tainted the public refuses to buy fish from that area and the entire fishery is impaired. With the development of the petrochemical, synthetic organic, and other new industries, tainting has become more intense and widespread. Continuous flow bioassays are needed to determine the materials which taint the flesh of fish, oysters, shrimp, and other aquatic organisms used as food and the maximum concentrations which do not cause off flavors in the flesh. These levels can then be established as criteria for control of the problem.

Dispersed Pollutants

Conventionally, when we consider pollution abatement we think of treatment plants for the handling of municipal and industrial wastes. These wastes have a "point source" or they are collected from a specific locality and brought to a plant from which the treated effluent is discharged to the stream as a "point source" of waste. However, several groups of potential pollutants cannot be considered or handled in the conventional manner. These are the increasingly important wastes or contaminants which enter our waters from the entire watershed or a large portion of it and thus are not amenable to conventional collection and treat-

ment methods. If the pollutional effects of these wastes are to be controlled, control measures must be directed at their source. Among these wastes are, (1) materials eroded from the watershed; (2) radioactive fallout washed from the land area; (3) return irrigation water; and (4) pesticides applied to water areas, or which drift onto water areas during treatment of adjoining land areas, or which are washed in from the watershed.

Water pollution by these four types of wastes constitutes a very broad and difficult problem which can be solved only by the cooperative efforts of all concerned. Many federal and state agencies as well as local groups and individuals are concerned with these problems and all must earnestly work for abatement if they are to be controlled.

In the broad field of the biology of water pollution we must not be unaware that poor land management causes pollution and seriously affects the productivity of our waters. Eroded materials are our most universal and perhaps the most important pollutant over most of America. Dissolved solids which serve as fertilizing materials may cause intense algal blooms and other nuisance conditions. Solids may cause undesirable turbidity and may seriously impair the productivity of benthic areas. When solids settle out they assist in the production of sludge beds, interfere with natural purification, prevent reproduction, fill pools, destroy cover, and choke streams or fill lakes and reservoirs.

Wastes of this type are controlled by preventing their entry into the stream through erosion control and good agricultural and other land use practices. Research and operations directed toward the control of soil erosion are being carried on by a number of federal and state agencies. These efforts can be aided and related to pollution abatement through educational programs.

Due to increased fallout and the industrial use of radioactive materials, radioactivity in our waters is assuming greater importance. Studies are needed to determine where, in what organisms, and to what extent these materials are being concentrated and the levels at which they become harmful to the aquatic biota. Criteria as to the allowable levels for such materials are needed.

With more widespread and intensive drainage and other activities in connection with land use, has come progressive lowering of the water table. This depletion of ground water has progressed to the point where irrigation is in use or is being considered in many areas of the humid east. Extensive consumptive use of water for irrigation can cause streams to dry up or to become so low that serious destruction of the aquatic habitat and life results. Reduction in flow lessens the stream's ability for self purification and causes greater concentration of toxic materials. Return irrigation waters are often high in dissolved solids and, as previously mentioned, warmer than the stream water. Such water can render a stream unfit for trout and the other Salmonoids. Similarly as in erosion prevention, many groups are involved in this difficult problem for which good land management is the best approach.

Pesticides (including insecticides, rodenticides, herbicides, fungicides, etc.) are now so widely used they are becoming serious water pollutants in many areas. An ever-increasing number and quantity of new and more toxic materials are broadcast over extensive areas for the control of forest and agricultural pests. Research should precede the widespread use of these materials but is lagging far behind. The toxicity of some of the newer materials is not known for even a few of the aquatic species. Of the synthetic organic pesticides now in common use, DDT has been studied most intensively, but toxicity data are available for only a few species. There is immediate need for information on the toxicity to the aquatic fauna of all the pesticides now in widespread use.

If our aquatic life is to be protected we must determine the concentrations of each of these materials singly and in combination with other materials which are safe for the aquatic biota. Not until these levels are known can water quality criteria be set up for the protection of aquatic life and the prevention of pollution. Since the meager data now available indicate that concentrations of some of these materials lethal to different species of fish may vary by more than five hundredfold, it is apparent that allowable concentrations must be based on toxicity to the most sensitive species and developmental stages. Careful attention must also be given to synergistic effects as evidence shows these can be quite important.

Since lethal concentrations of some of these materials are in the range of a few parts per billion, or in a fraction of a part per billion, it may be that they should not be broadcast and it is certain that they should not be applied directly to water areas even at a small fraction of the dosage commonly used on land areas. With this type of pollution, abatement can be attained only through rigid control of the kinds and amounts of materials used and by giving preference to the use of those materials which are less toxic to aquatic life.

DISCUSSION

In carrying out a research program directed toward the abatement of water pollution, certain basic investigations should be undertaken in proper sequence. First, is the determination of the water quality characteristics essential for each of the beneficial uses of water. These serve as the bases for water quality criteria, which in turn are the bases for the definition of a satisfactory water. Without such criteria water pollution cannot be clearly and effectively demonstrated. Research workers should realize that these essential facts are the first bulwark of defense against pollution. Not until water quality characteristics for each beneficial water use are clearly and concisely defined and backed with adequate data will it be possible to demonstrate effectively the existence and extent of water pollution or evaluate pollution abatement measures. Facts must be set forth in readily understandable form and must be widely disseminated so that administrators, government officials, industrialists, control workers, and the public will understand and appreciate their application in pollution abatement.

To be effective water quality criteria for the protection of aquatic life must be based on the environmental requirements of the aquatic biota and must insure the maintenance or restoration of environmental conditions essential for survival, growth, reproduction, and well being of the important organisms in the biota. A knowledge of the environmental requirements of the biota is a prerequisite for the establishment of such water quality criteria. The determination of the environmental requirements of the important organisms in the biota will require a manifold expansion in our present research effort. Research on lethal levels, conditions which can be tolerated for only a short time,

conditions essential for the general well being, and the interrelation of various habitat conditions should have high priority and should be encouraged in colleges, universities, and governmental agencies.

SUMMARY

The acquiring of data essential for the formulation of water quality criteria for the protection of aquatic life will require research in several fields to determine:

1. Turbidities which inhibit basic productivity, turbidity tolerance of important species of phytoplankton and rooted aquatic, and the extent to which different turbidities interfere with reaeration by photosynthesis.
2. Temperatures which are lethal to or limit certain species, temperature levels throughout the seasons which are conducive to the general well being and various levels of productivity, and temperatures most favorable for the desired species.
3. Oxygen requirements of at least the important species of the aquatic biota; lethal levels, concentrations which can be resisted for a time and levels essential for the general well being under conditions of continuous exposure.
4. The effects of temperature, pH, and various dissolved gases, liquids, and solids on minimum and favorable dissolved oxygen concentrations.
5. Levels of pH which are limiting and which are favorable and the effects of pH on other environmental factors, especially the toxicity of various materials.
6. The toxicity of complex wastes and other materials to the aquatic biota under conditions of short term and continuous exposures.
7. Sublethal and long-term physiological effects of toxicants on important members of the biota and the biological balance in the waters with special consideration to sex, age, season, and competitor, predator, parasite, and disease relationship.
8. Modes of entry of these materials into the body, methods for detecting and measuring

these materials in the body, and the body burden which is lethal.

9. Methods for the development of application factors which can be used with short term bioassays or physiological or other studies to indicate safe levels of a waste under conditions of continuous exposure.

10. For all new pesticides prior to use: their acute toxicity to important members of the aquatic biota; their residual properties; their inactivation or rate of adsorption in different soil types; formulations, methods, and times of application least harmful to the aquatic biota; toxicity under conditions of continuous exposure and amount which can be applied to water surfaces and different types of land areas without significant harm to the aquatic biota.

For the prevention of water pollution by pesticides it appears that research should be directed not toward the development of more toxic wide spectrum material but to the discovery of more specific materials for those organisms for which control is necessary.

While research for the securing of data necessary for the establishment of water quality criteria is under way present information should be used to establish tentative criteria to apply the information now at hand for the protection

of the biota with the idea such criteria will be improved as more data become available.

When criteria based on available information have been established, the next task is to develop procedures for rapidly detecting and measuring pollutional effects and conditions. Studies which use the aquatic biota as indicators of past environmental conditions are of great value. Physiological studies are also of outstanding value in detecting and evaluating sublethal effects. Chemical methods are needed to detect various materials in water and to determine if water quality criteria are being met by those discharging wastes.

Pollutants which originate not from a "point source" but from a large segment of a watershed require a somewhat different approach. In this instance control must be exercised at the source. Silt due to land erosion is an outstanding pollutant of this type as is pollution by pesticides. Pollution by pesticides can be prevented only by controlling the kinds and amounts of materials which are applied.

Periodic biological surveys are the best tool for detecting pollution of the aquatic environment and evaluating its effects. They are also one of the best methods for determining if those discharging wastes to our waters are complying with requirements for the protection of aquatic life.

SUMMARY OF SECOND SEMINAR ON BIOLOGICAL PROBLEMS IN WATER POLLUTION

Ernest Swift, Executive Director - National Wildlife Federation,
Washington, D.C.

I appreciate the confidence in me of those who requested I summarize and draw together the general meaning and the essence of this meeting.

I can assure you the meeting has been very stimulating to me.

Frankly, it has stretched my thinking and imagination. I will readily admit I was unfamiliar with many of the professional terms. If you had been discussing forestry, I would have understood the meaning dominate and co-dominate species, of understory, natural reproduction and D. B. H. I have a good working knowledge of game management terms, but in this instance I had to swim hard to keep my head above water--and it was good for me. Possibly there are some others who could be classified along with me.

Because of the broad scope--although within the confines of the general subject--I have asked each panel chairman to recapitulate the topic of his panel.

Collectively I am sure the group will gain more than if one person attempted to emphasize the multiplicity of high lights and enumerate the many splendid contributions by all the panel members.

It appears to me that many aspects of resource management have been indirectly touched on, although the hard core and theme is water; its use and abuse.

These issues are being discussed because they affect our daily lives--and included have been discussion on the discharge of effluent, radioactivity, aquatic life, forestry, agriculture, the use of chemicals as they affect water, and in turn how all of these may affect human beings.

Reserving a little time for myself at the end I will now call on the panel chairman.

* * *

I doubt if there is need to reiterate any justifications for research--or the over-all effort which this group--or others in the field--are doing, or what you or they represent as it affects living today, tomorrow, and we hope for some time to come.

As I see it, a vital question to be asked, is: How can the findings of research be made operative and effective?

Granted we have some of the tools and increasing talents, there is always a need for funds. Dollars to save in part, at least, values we do not always care to standardize on the dollar basis.

We have all heard endless debate on public spending. Also, debate on what constitutes valid reasons for public spending.

In regard to public spending, Congress and the State Legislatures devote much of their time attempting to solve that problem, so I will confine my remarks to the need for spending to protect resources.

A good question to ask also, is: How much should private sources spend to protect resources?

When resources are privately owned by whomever it may be--the farmer, ranger, forest owner, mine operator--we applaud them if they practice good husbandry. When they fail or are indifferent to good resource husbandry--we bribe them with various types of subsidies. In either event, public or private money and in-

come is spent to protect the individual's investment.

Seldom--too seldom--do we ever penalize them in the name of public interest; there are a few exceptions.

But would it not be a sound business proposition to spend more money for good husbandry of those resources which we collectively own?

Appropriations to protect public resources, such as public domain and public water, usually get rough going. Appropriations to subsidize individuals who control resources and who in turn can vote and demand more subsidies receive more kid glove attention.

The old saying that public business is nobody's business rings true in this instance.

Our biggest national investments should be in the husbandry of all resources, and certainly those which we collectively own should receive equal consideration with those owned privately or privately owned and publicly subsidized.

And when I use the term husbandry I include everything from basic, long-range research to its application, and resource management, including their uses.

TO DENY MONEY FOR THE HUSBANDRY OF OUR RESOURCES CONSTITUTES NATIONAL SUICIDE.

Whether you work for private industry or a public agency, you have the common problem of financing.

Money for research must be justified to those who control the purse strings, like any other budgetary item.

Therefore, whether you like it or not, you have a selling job to the man above you. To do this you must be aggressive, articulate and know your subject. Vagueness has probably destroyed more research budgets than any other human failing.

Now the man above you must take your facts and along with many other items, resell them to a board, a commission, a foundation or a legislative committee.

To some people this is a distasteful job. Some are not cut out for it, but that shouldn't stop you from working at it and learning how. In public life, as you well know, your budget may get into partisan politics.

Resources cannot vote, but the people who wish to control them can, and the merit of a case is often determined by the impact of a group and not what is good for the resource.

If you believe in your cause then when necessary get into the bloody arena and fight for your cause.

That is our philosophy of life--our form and operation of government.

You will either do it by some means or other or lose a fight.

There is another selling job that takes team work. That is to see that your findings and efforts come to some beneficial use. Proving their use will be reflected in appropriations.

If at all possible a man of experience will choose his own battle ground, his weapons and his time to fight. That strategy is fundamental.

Making these determinations takes judgement and patience.

I recall when I was the Director of the Wisconsin Department some of the research boys reporting to me on the results of a study which had taken the better part of four years.

We all felt the findings conclusive. The boys in management and research both recommended immediate action.

But I told them that in view of the fact that it had taken nearly four years for them to arrive at an answer, why not take a little more time and prepare the public. If it had taken them four years to arrive at a conclusion then the public was entitled to some time, for after all the public was paying the bill. I suggested we condition the public by publicizing the results of the study to develop support, instead of getting into a rear guard action of attrition. I have seen the latter happen many times for lack of public relations.

What it amounts to is educating the public--but I hesitate to use that terminology. People

resent the idea that they are being educated--it implies they are ignorant. The same results can be obtained by using a different phrase or term. Even public relations as a slogan has become shopworn.

However, I do not favor a heterogeneous mass of materials being stuffed down the public throat, like force-feeding a Christmas goose with noodles. It would only tend to emphasize a truism by Josh Billings: "It ain't that people are ignorant, it's jest that they know so many things that ain't so!"

As the saying goes; We learn more and more about less and less.

Big government, big business and big labor tend to regiment the role of the specialist along with the rest of us mortals.

If the specialist doesn't fight against regimentation, he begins to view the entire world through the key hole of his one specialty.

When the specialist begins to disregard the complexities of this vast field of natural phenomena and the whole ecology of organic and inorganic elements--other than his own specialty, what can you expect of the public?

Without too much thought or background the ordinary individual will choose the gospel of the specialty which appeals most to him, without much regard for other considerations. When once he has made up his mind, it is hard to change it.

The public--often accused of ignorance and indifference--may give you the seven year itch but the public is far more intelligent than given credit, if it has facts upon which to base decisions.

We should not be attempting to make specialists of the public--they will assume that role without your help--but we should engender the proper philosophies and sympathetic attitude to support good conservation precepts in general.

In drawing toward a close and returning to the basic theme--it would seem that this seminar has shed light on the many ways which man's inventive genius has contributed to the pollution of water.

His enthusiasm for polluting far outdoes his desire to overcome it.

Man doesn't realize it but he has a wildcat by the tail--and he can't let go.

In what manner can we convince people that clean water is synonymous to survival? One way is never to admit defeat and when we take a licking just figure we are backing up for a new start.

The opposition at times seems to have overpowering arguments.

The overwhelming developments of an industrial revolution, plus an exploding human population has brought problems, fears and frustrations undreamed of fifty years ago.

This fact has repeatedly been brought out in the panel discussion and with different and sometimes opposing viewpoints.

I long ago felt the impact of some of these weighty problems in my own state where, for example, paper making is a billion dollar industry. The whistles of the mills are not going to be stopped and the machinery tied down while all the diverse and difficult secrets to the solution of pollution abatement are uncovered.

And I must say that some of the mills are spending much time and effort with the public agencies to improve conditions; and I will also say that some are not.

At the state level there could be improvement by centralizing power and authority providing it is the proper kind. In my old state the pollution board is composed of civil service employees with vast and far-reaching power.

The justification for federal legislation and federal aids is also hotly debated.

In the case of pollution the extension of federal authority and the use of federal funds stems primarily from the fact that the states have not insisted on pollution abatement, and have refused to exert their authority. This is due to many obvious reasons. But, nevertheless they have abrogated their sovereign powers.

In the states where the riparian doctrine exists, there has not been sufficient emphasis on

the fact that lakes and streams are public property -- therefore public domain. Polluters in many cases are trespassers.

Every man, woman and child has an equal equity in a state's public waters. You people of Ohio--read the ordinance of 1787--establishing the Northwest Territory and you will find that your navigable streams are public highways. Highways, in a sense, are also public domain, but industrial plants and municipalities, so far, have not attempted to dump their sewage on the highways.

I have long listened to the argument that the only standard by which resources can be evaluated is economic--the dollar standard.

This is a strategy to place other values such as recreation and esthetic values in a defensive position and if they cannot balance the scales

alongside the dollar then they are looked upon as having doubtful worth.

The word emotionalism is constantly applied --overworked, in fact--to the person who cannot stack his esthetic values alongside the dollar. The word emotional means unstable in varying degrees, and some people who worship the dollar standard solely use it as a nasty word--as if a person valuing the esthetics of nature is a pervert of sorts, but I wish to observe that I have seen far more emotionalism displayed through the loss of a dollar than I have ever witnessed through the loss of an esthetic value. Back in the crash of '29 and '30 there were suicides because of the great dollar losses-but this has never occurred over esthetic losses.

This has been a highly stimulating meeting to me; and I am sure to all of us. I wish to thank you for your attention.

INFORMAL GROUP DISCUSSION

BIOLOGICAL INDICATORS OF ORGANIC ENRICHMENT IN FRESH WATER

Discussion Leader

A. R. GAUFIN
University of Utah
Salt Lake City, Utah

Aquatic organisms have been used for many years as indicators of the ecological conditions under which they exist. The aquatic population which occurs in a given area is representative of the environmental conditions which have prevailed during the life history of the organisms comprising the population. If at any time during its development, environmental conditions become lethal for a given organism, that organism will be eliminated even though the unfavorable conditions are of very short duration. This property of indicating past environmental conditions makes some aquatic forms, especially the macro-invertebrates, valuable indicators of the amount and duration of organic enrichment in fresh water.

In order to utilize aquatic organisms as indicators of organic enrichment the species composition and abundance of the various organisms in the populations involved must be considered. In general a population containing numerous gill breathing forms as mayflies, stoneflies, and caddis flies is indicative of clean water conditions and their absence denotes an abundance of organic materials and/or low oxygen. By contrast, the macro-invertebrates most characteristic of heavy organic enrichment are those which can exist in water with very low oxygen concentration or have adaptations for breathing atmospheric oxygen.

The numerous lists of indicator organisms which have been published since Kolkwitz and Marsson's early classification (1908-1909) may have popularized their use to an unjustifiable degree. Comparison of these different lists will show that there is an appreciable lack of agree-

ment as to the true status of many of the organisms. This lack of agreement is a result of regional differences in the species present and in the environment, and is conditioned by the point of view of the investigator, the mechanism of evaluation, the type of pollutants, and other factors. Because of regional differences in the species present, a list of indicator organisms applicable to one section of the country may have very little value in another area. Similarly, a method for using indicator organisms developed in one section of country may not be adaptable for use in another section. Thus, Beck's system, while excellent for classifying invertebrates from Florida's streams, did not work well in classifying Ohio or Utah fauna.

Another complicating factor in the use of indicator organisms is that some species may become more tolerant to certain pollutants by continuous exposure. In addition, closely related species of the same genus may display a vast difference in their tolerance levels. Thus, the author has found some species of the mayfly genus, *Baetis*, to be very sensitive to low oxygen levels and other species in the same genus to be able to tolerate the same or worse conditions.

In conclusion, before much reliance can be placed on presently existing "lists" of indicator organisms considerably more research will have to be done to determine just exactly what individual indicator species indicate.

BIOLOGICAL INDICATORS OF ORGANIC ENRICHMENT IN MARINE HABITATS

Discussion Leader

J. L. MOHR
University of Southern California
Los Angeles, California

Designation of indicators of marine enrichment has lagged behind parallel work on fresh water organisms. So far most marine areas

concerned have received small amounts of waste compared to the mass of receiving waters (notable exceptions such as Oslofjord may be noted), critical levels even now only threatening. Even where damage is suspected or feared, the difficulties of knowing the organisms and of comparing either different habitats in one area or one area with another are of a different order than those of inland waters. The variety which confronts the marine biologist (representatives of all phyla and most classes and orders) is hard for a mid-continental biologist to imagine.

In "areas of marine enrichment" several quite distinct major environments are involved. First are estuarine waters where continuous or seasonal run-off of fresh water limits the biota to euryhaline species. In North America such areas are characteristic of the east coast and of the west coast from San Francisco Bay northward. Second, there are certain harbors and enclosed bays which have moderate to negligible changes in salinity and limited water circulation compared with the third and fourth categories. San Diego Bay, Los Angeles - Long Beach harbors and waters of Florida and Texas protected by long spits are examples of these. Third, there are open coastal areas receiving great urban sewers such as the White's Point (Los Angeles County) and Hyperion (Los Angeles City) outfalls and the discharges of certain paper mills. Finally, there are open sea areas to which industrial acids and other wastes are carried by barge from the New York and San Francisco Bay areas. Intermediate areas exist among these general ecological situations. Within each major area there are strikingly different populations dependent upon bottom (silt, sand, rock), currents, and probably upon latitude. These factors controlled populations before man became an ecological influence. For North America the differences in breadth of continental shelf and degree of serration as well as different relationships to the great oceanic movements make for very different conditions and the conditions for different biotas on the Atlantic, Gulf, and Pacific Coasts.

With presumption of differences of such high order, first need is to see whether there is any agreement among those operating in different areas. There was general agreement that benthic or settling organisms (fouling in another context) are the only ones likely to be useful indicators. Among these, Kneeland McNulty (University of Miami, working in an estuarine

area in Biscayne Bay with waters to 10 feet, domestic sewage being the principal pollutant) was the only one to report use of plants as indicators. He found attached algal populations notably modified in polluted, and especially in turbid waters. With turbidity, red algae, generally found only in considerably deeper water, became dominant.

The effects of enrichment on marine animals have been observed more widely. In all areas the characterization of natural (primeval) conditions presents major difficulties. C. E. Dawson (Gulf Coast Oil Co.) noted that areas in which oil drilling platforms are about to be or are newly established on the Gulf coast either in estuarine or open water areas provide an opportunity to follow development of sedentary populations under changing conditions.

McNulty emphasized the need of examining bottom communities under influence of pollution, citing particularly the Danes, Petersen (1911) and Thorson (1957). Having followed a number of animal groups in Biscayne Bay (about 200 stations in an area 10 by 15 miles using Petersen or van Veen grabs as samplers), he concluded that echinoderms, being highly sensitive to low dissolved oxygen, are excellent negative indicators; certain mollusks, arthropods, and annelids, present throughout the area, thrive particularly in areas of domestic pollution. He noted seven species of amphipods, most of them tube makers, in areas of high turbidity (Barnard, pers. comm., has noted that in Los Angeles - Long Beach Harbors, certain *Corophium*, *Erichthonius*, and other tube dwellers are indicators of turbidity).

Southern Californian experience also shows that effects of pollution may be marked best by changes in community structure. In harbor areas comparable with Biscayne Bay, Reish has found a series of communities characteristic of various levels of pollutions in a way gratifyingly parallel to the complexes noted by Tarzwell and Gaufin in fresh waters. Up to the intensities at which pollution eliminates animal life, as pollution increases there are increasing numbers of individuals of fewer and characteristic species, notable among them the nearly cosmopolitan polychaete, *Capitella capitata*.

The Allan Hancock Foundation's survey of offshore waters of the southern Californian coast for the State Water Pollution Control

Board of California is providing the first extensive views of animal communities in an open coastal area receiving large waste discharges. Reports on these will appear as publications of the Board. At least in a general way the tendencies pointed out by Tarzwell and Gauvin for fresh water and Reish for certain harbors appear to apply to this open coastal area although the picture is less sharp and more complex. Both harbor and coastal waters appear to have more varied populations than those reported from Biscayne Bay by McNulty. The differences are great enough to suggest that exchanges of visits would be desirable for comparison of methods and results. Hartman (1956) has pointed out that sorting techniques are actually more important than sampling devices in determining what is ultimately recorded. It should also be noted that in all the surveys, only the medium-sized to large organisms have been studied except by the few individuals who have exposed slides (a method not generally useful in open water). These organisms are not so close to

the wastes discharged as are the microbes, whether bacteria, protozoans, or the many small metazoans: nematodes, rotifers, annelids, arthropods, mollusks, and others. It may be that we should be paying closer attention to the microbiotas. In this regard it is good to be able to report that one of Dr. Tibby's group in the Hancock Foundation Survey is making a critical study of foraminiferans at their various stations (work supported by the U.S. P. H. S.).

The last area, relatively deep water dumping sites, has not been studied for faunal changes although concern has been expressed about areas of dumping of radioactive wastes.

We may summarize by noting that only a beginning has been made in a search for indicators of marine enrichment, that so far analysis of communities has appeared more useful than the marking of single index species, and that reports from different areas have had as many differences as likenesses.

ADVANCED SPECIALIZED TECHNICAL TRAINING IN POLLUTION BIOLOGY

Discussion Leader

H. W. JACKSON

U. S. Public Health Service

Robert A. Taft Sanitary Engineering Center

The first problem pointed out is that of retaining adequately trained men in the field as biologists. Men who are well enough equipped to function effectively as biologists are frequently lured out of the field by industry or other agency as chemists, often even before biological training is completed. This is understandable in individual cases, but regrettable professionally, as the requisites for a well trained biologist include a thorough grounding in chemistry, physics, and mathematics (especially statistics). It was the consensus of opinion that wider recognition of biology as a profession leading to a higher pay scale would help.

Specific conclusions and suggestions were as follows:

1. Advanced technical training in the field of pollution biology is so highly specialized that very few colleges or universities could afford to offer a complete curriculum.

2. The present training program at the Sanitary Engineering Center should be continued and encouraged to meet the need for post graduate training in pollution biology.

3. Colleges should avail themselves of reference copies of training manuals as available from the Sanitary Engineering Center for use as reference material.

4. Graduate students might obtain financial support for attendance at SEC courses from financing agencies such as the National Science Foundation.

5. A special offering of one or more courses by the Center would probably not be practical due to the difficulty of finding a two-week period which could be spared from the average graduate program.

6. It would be highly desirable for the Center to outline minimum academic requirements for a career in pollution biology.

7. It was pointed out that the Center stands ready to consult with colleges and universities in regard to training in biological aspects as well as other aspects of Sanitary Engineering, and to assist in any way possible. The regional summer institutes were recommended to college faculty members.

8. It was also agreed that much more effective use might be made of pre-college years to speed up the education of American youth, so that college level work could start in the freshman year. Failing this, more and more five-year undergraduate programs may be expected.

IDENTIFICATION OF TOXICANTS BY PHYSIOLOGICAL RESPONSES OF FISHES

Discussion Leader

CHARLES M. WEISS
University of North Carolina
Chapel Hill, North Carolina

The problem of response of fish to toxicants and their identification by specific sub-lethal physiological changes was introduced by the discussion leader with a review of some recent work of Schiffman and Fromm¹, external reactions to specific toxicants that have been reported by other investigators, Henderson and Pickering² and Weiss and Botts³ and a report on studies by Weiss⁴ in which a specific enzyme inhibition is used to describe the sublethal toxic action of organic phosphorus insecticides on fish. It was pointed out that the response of fish to toxicants as evidenced by external symptoms is a secondary reaction resulting from interaction with some physiological system. The problem then becomes one of locating the site of primary toxic action. If techniques of measuring the degree of change from normal of this primary physiological system could be worked out, then chronic and sub-lethal exposures could be demonstrated as well as the possibility of specific identification of the toxic compounds if the toxic action was through a specific physiological system. It was essential to "get inside the fish".

The procedure described by Weiss for the specific identification of organic phosphorus insecticides is based on the selective inhibition of the enzyme acetylcholinesterase by these insecticides. In this procedure the fish brain is homogenized and allowed to react with .004 M acetylcholine in a suitable buffer (pH 8.2) at a tissue concentration of about 3.5 mg/ml. The acetylcholine is split by the action of the enzyme and after 20 minutes incubation at 25°C the residual acetylcholine is determined colorimetri-

cally. The activity of the enzyme is reported in terms of units representing micromoles of acetylcholine split per hour per mg of brain tissue (wet weight). The normal activity of the fish brain is determined for each species and in the range of sizes normally encountered or used for the species. The normal activity per unit brain weight shows a negative regression when plotted against total brain weight. The curve of best fit for normal activity is then used as the reference for determining percentage changes when exposed to organic phosphorus insecticides.

It has been found that the degree of inhibition of fish brain cholinesterase is a function of the concentration of the insecticide, extent of exposure and specific chemical nature of the inhibiting substance. Fish removed from exposure to the acetylcholinesterase inhibiting insecticides prior to reaching lethal limits, demonstrate the capacity for regeneration of the brain enzyme. The time required to regenerate the brain acetylcholinesterase to normal levels will depend on the extent of the initial inhibition, the specific nature of the compound which produced the inhibition and the particular fish species. The regenerative period may be as long as 40 days or more.

Of some eight organic phosphorus insecticides examined, parathion produced in exposed fish a continued decrease in brain acetylcholinesterase activity after removal from direct exposure. The decrease continued or brain enzyme activity was maintained at a low level, for as long as ten days in the post-exposure period. Post-exposure changes in the brain enzyme varied also as a characteristic of the fish species. For example, bluegills exposed to Guthion showed immediate increase in brain enzyme activity in the recovery period reaching normal levels in eight to ten days whereas largemouth bass exposed in a similar fashion to this compound showed a ten-day lag in the regenerative period before brain enzyme activity started to rise to normal levels which had not been attained by the twentieth day of recovery.

The specific *in vivo* response of the fish brain acetylcholinesterase to low concentrations of organic phosphorus insecticides (in the magnitude of 0.1 p.p.m. and lower) permits their use as an assay of current or past contamination of waters in which the fish might be found or be introduced.

In the discussion following Weiss' presentation, George E. Burdick of the New York State Conservation Department noted that from the enforcement agency standpoint, legal action is currently only feasible when death of fish has occurred. The use of chronic or sub-lethal effects would require either redefinition of the pollution regulations or a broader interpretation of existing laws.

J. R. Brett of the Pacific Biological Station, Nanaimo, B.C., observed that fish exposed to sulfate mill waste exhibit respiratory distress at levels not toxic in 10,000 minutes. The fish were exhibiting a chronic or sub-lethal response to the foreign material. The question that was then raised was what is a safe level? Brett also noted that under stress conditions the response of fish to sub-lethal concentrations of toxic materials was considerably different than under normal or resting conditions. The problem of physiology of stress in fish requires considerable study in order to elucidate the biochemical relationships that exist when fish are exposed to toxic materials.

It was the general consensus of opinion of the group that the general problem of pollution would be material enhanced by an understanding of the biochemical systems of fish which lie in the primary line of response to toxic materials.

REFERENCES

1. Schiffman, R. H. and P. O. Fromm. 1959. Chromium-induced Changes in the Blood of Rainbow Trout, *Salmo Gairdnerii*. *Sewage and Indust. Wastes* 31:205-211.
2. Henderson, C. and Pickering, A. H. 1957. Toxicity of Organic Phosphorus Insecticides to Fish. *Trans. Amer. Fish. Soc.* 87:39-51.
3. Weiss, Charles M. and James L. Botts. 1957. The Response of Some Freshwater Fish to Isopropyl Methylphosphonofluoridate (Sarin) in Water. *Limnology and Oceanography* 2:363-370.
4. Weiss, Charles M. 1959. Response of Fish to Sub-lethal Exposures of Organic Phosphorus Insecticides. *Sewage and Industrial Wastes* 31:5, 580-593.

POPULATION CONTROL BY CHEMICALS AND SOME RESULTING PROBLEMS

Discussion Leader

FRANK F. HOOPER
Institute for Fisheries Research
Michigan Department of Conservation
Ann Arbor, Michigan

While some conservationists have loudly condemned the newer insecticides because of their destructive action upon wildlife, other workers in conservation have found important uses for certain of these compounds in the management of fish populations. It is now known that many of these substances are extremely efficient fish-killers and possess properties which make them a valuable addition to the fisheries managers' kit of tools. The purpose of this paper is to describe the use of one of the newer, chlorinated hydrocarbon insecticides as a fish toxicant and to discuss certain problems that have arisen from its use in fresh-water lakes and ponds. It is important that information on the use of such materials in fisheries management be widely distributed, since increased usage can be expected in the future.

A variety of chemicals have, from time to time, been used to eliminate undesirable fish. Titcomb (1914), Catt (1934), and others have successfully used copper sulphate as a toxicant in soft-water regions. Cresol is a quick-acting toxicant which has found use in sampling populations of stream fishes (Embrey, 1940; Wilkins, 1955). Free chlorine from HTH powder or similar compounds, and anhydrous ammonia have been suggested as fish toxicants.

Although all of the above compounds have found some use in fisheries management, fish toxicants were not used extensively until the insecticide rotenone was shown to be a practical and powerful toxicant. Rotenone was first used in this country in 1934, and since that time has found wide acceptance. With the use of rotenone, the practice of eliminating undesirable fish and replacement by desired species became well established throughout the United States. Michigan now uses between 3,000 and 6,000 gallons of rotenone-bearing fish toxicants each year and much higher figures are given for other states.

As much as 105 tons of rotenone powder has been used in a single fish-eradication experiment. Although the toxicity threshold of rotenone differs slightly among fish species (Burdick, Dean and Harris, 1955), it has never been widely used as a selective toxicant. Although toxic to man and warm-blooded animals (132 milligrams per kilogram), rotenone has not been considered hazardous in the concentrations used for fish eradication (0.025-0.050 parts per million of active ingredient). Hence it has been employed in waters used for bathing and, in some instances, in drinking water supplies.

Rotenone is a relatively quick-acting toxicant. In most instances, fish die in one to two hours after exposure. It appears to be subject to rapid breakdown in most lakes and ponds (Clements and Martin, 1954). At a higher temperature range, toxicity can be expected to last for 24 hours or less. Breakdown is so rapid that in many instances toxicity is lost before the toxicant is distributed throughout the water mass. Thus fish kills are incomplete and some of the undesirable species remain, which means that retreatment is necessary. To avoid detoxification before the chemical is mixed throughout the lake, it must be well distributed with spraying equipment. Cost of rotenone varies somewhat depending on what formulation is used but in most instances does not exceed approximately \$1 per acre foot of water treated.

Principal needs in a toxicant that would supplement or replace rotenone are: (1) a slower breakdown rate in fresh water, which would allow the toxicant to mix thoroughly throughout the basin by natural water movements; (2) lower cost, making population control economically feasible on larger bodies of water.

NEWER ORGANIC INSECTICIDES

Use of the newer insecticides on field crops and subsequent drainage into ponds and streams led to the discovery that these substances were highly toxic to fish (Lawrence, 1950; Young and Nicholson, 1951). Toxicity data for fish for most of the new organic insecticides are now available (Doudoroff, Katz, and Tarzwell, 1953; Henderson and Pickering, 1958). Compounds of the organic phosphate type are less toxic to fish than the chlorinated hydrocarbons (Henderson and Pickering, 1958) and have been rejected as fish poisons (Hayes, 1955). Of the chlorinated

compounds, toxaphene (chlorinated camphene) has received the most attention. The chemical has been used for approximately ten years. It was an ingredient of a fish toxicant sold under the name of "Fish-Tox" (Tanner and Hayes, 1955). More recently, forms of the toxaphene sold for agricultural purposes have been used. The most popular is an emulsion which is marketed as a livestock spray.

TREATMENT OF LAKES WITH TOXAPHENE

The usual practice in treating lakes is to dilute a toxaphene emulsion 5- to 10-fold with water. The diluted chemical is then poured on the surface of the lake in the wake of an outboard motor or is pumped or sprayed on the surface or underwater. For most lakes, elaborate equipment for mixing and spraying is not required since natural water movements can be depended upon to distribute the mixture throughout the basin. Because of its high toxicity, considerable care is exercised in handling the concentrated chemical. Eyes and skin should be protected at all times when either the diluted or concentrated chemical is sprayed from the boat.

At low temperatures and near the toxicity threshold, action of toxaphene upon fish is very slow. Below 50°, a week or ten days may elapse before fish show distress symptoms. The die-off of fish may then continue for three weeks or more. At 70° on the other hand, most of the fish will die within a ten-day period. Distress symptoms of affected fish are erratic and uncontrolled swimming movements. Often fish will swim to shore and strand themselves. Erratic respiratory movements follow, and death is probably due to respiratory failure.

The concentrations of toxaphene in treating lakes have varied from 2 to 100 parts per billion (Table 1). Concentrations between 2 and 7 p.p.b. appear to affect only the small fish (Fukano and Hooper, 1958). At concentrations greater than 7 p.p.b., complete kills can be expected in the deeper lakes (Stringer and McMynn, 1958). In Michigan, partial kills have been noted in shallow lakes at concentrations as high as 15 p.p.b. Failures at concentrations as high as 50 p.p.b. have been reported in other areas (R. F. Harris, Wisconsin Department of Conservation, personal communication; Tanner and Hayes, 1955).

Table 1. Lake Treatments with Toxaphene, 1954-1958.

Lakes treated with the commercial preparation, Fish-Tox,
have not been included

Concentration range (parts per billion)	Number of lakes	Location	Fish kill	Approximate duration of toxicity (months)	
				Range	Average
Nontrout lakes (mean depth less than 13 feet)					
2-7	6	Michigan	Partial	...	...
7-15	3	Michigan	Partial	...	...
	2	Michigan	Complete	2-5	3.5
16-25	7	Michigan	Complete	2-11	6.3
26-50	1	Michigan	Complete ^{1/}	<u>1/</u>	<u>1/</u>
51-100	4 ^{2/}	Michigan	Complete	2-11	8.0
	2	Iowa ^{3/}	Complete	2-5	3.5
	1	Arizona ^{4/}	Complete	...	< 6
	1	Colorado ^{5/}	Complete	...	7+
Trout lakes (mean depth greater than 13 feet)					
5-15	1	Michigan	Partial	...	...
	2	Michigan	Complete ^{1/}	<u>1/</u>	<u>1/</u>
	2	British Columbia ^{6/}	Complete	...	9+
16-25	2	Michigan	Complete	12	12
26-50	2	Michigan	Complete	18-42 ^{1/}	...
	2	British Columbia ^{6/}	Complete	...	9+
51-100	4	British Columbia ^{6/}	Complete	...	9+

^{1/} Results incomplete, further tests required.

^{2/} Includes 2 shallow lakes subsequently planted with trout.

^{3/} Rose (1957, 1958).

^{4/} Hemphill (1954).

^{5/} Tanner and Hayes (1955).

^{6/} Stringer and McMynn (1958).

FACTORS INFLUENCING TOXICITY OF TREATED WATERS

The kill of fish achieved with a given dosage of toxaphene depends upon (1) concentration applied, (2) the rate of dispersion of the chemical through the water mass, (3) the rate of dissipation or breakdown of chemical, and (4) flushing rate or rate of water movement through the lake. The variability in results experienced in trials using identical concentrations (Table 1) are probably due to factors (2), (3) and (4). Incomplete kills may result from poor dispersion of the chemical in weedy and protected bays and backwaters, or from rapid chemical breakdown

so that it loses its potency before penetrating all parts of the basin.

Factors influencing the breakdown of toxaphene in treated waters have been discussed by Hooper and Grzenda (1957). Toxicity is lost most rapidly in the presence of light, high temperature and high oxygen, and more rapidly in water with high alkalinity than in soft water. In the laboratory, detoxification of water appears to come from the micro-organisms attached to the sides of the containing vessel and to other substrates that may be introduced. Sterilization inhibits the detoxifying action of substrates. The slow disappearance of the chemical from

lakes of great mean depth is perhaps due to the high ratio of water volume to area of bottom substrate. In a deep trout lake, several years may be required to bring enough water in contact with the bottom to detoxify the lake. Break-down appears to be rapid in highly turbid lakes, and Rose (1958) has suggested that lakes may be detoxified by artificially creating turbid water. Very likely, turbid waters lose their toxicity through the action of micro-organisms attached to particulate matter.

EFFECT ON AQUATIC INVERTEBRATES

Although there is an abundance of data on the toxicity of chlorinated hydrocarbons to terrestrial invertebrates, not much is known about the toxicity of these compounds to aquatic animals other than fish. Streams receiving run-off water containing toxaphene, DDT, BHC, or Aldrin lost most of their bottom fauna (Hooper and Hester, 1955). The 24-hour TLm of toxaphene for aquatic sow bugs (*Asellus*), scud (*Gammarus*), *Daphnia* and mayflies (*Ephemera*) appears to be greater than that for fish (Hooper and Grzenda, 1957). This is substantiated by reports that bottom fauna and plankton re-appear in lakes that have been treated with toxaphene before the lakes can be stocked with fish (Tanner and Hayes, 1955; Hooper and Grzenda, 1957).

It is clear that a major portion of bottom fauna is eliminated when lakes are treated with a concentration of 100 parts per billion of toxaphene. This dosage eliminated the midges from a Colorado reservoir (Cushing and Olive, 1957), and with the decline in midges, the oligochaete population increased. These authors believed that their toxaphene treatment was more destructive to bottom fauna than would result from rotenone application. In two Michigan lakes treated with 100 p.p.b., most of the invertebrates, except mollusks and oligochaetes, seem to have been killed. Following such reductions, it is clear that bottom fauna re-appears promptly. Most groups of invertebrates killed in an Alabama stream in 1950 had re-appeared by 1953 (Hooper and Hester, 1955). Both Michigan and Colorado lakes mentioned above were repopulated within 9 to 11 months, although the Michigan lakes had a reduced number of species.

At a concentration less than 100 parts per billion, there is less convincing evidence of danger to bottom fauna. Rose (1958) noted large

increases in midge populations in an Iowa lake following a dosage of 100 p.p.b. This build-up of midges presumably was due to release of the midge population from predation by bullheads. In Little Squaw Lake, a Michigan lake treated with a concentration of 10 p.p.b., the bottom fauna was nearly as abundant 14 days after application of toxaphene as before treatment (Table 2). The small decrease in numbers was due to the emergence of midges. Similar results were noted in treating a second Michigan lake (Sand Lake No. 2) at a concentration of 10 p.p.b. Stringer and McMynn (1958) found that midges were eliminated from lakes treated at 100 p.p.b. but survived in lakes treated with concentrations ranging between 10 and 70 p.p.b. Of the other invertebrates sampled by these authors, the only ones eliminated at concentrations of 10 p.p.b. were amphipods (*Gammarus* and *Hyaella*). The higher concentrations in earlier experiments (100 p.p.b.) must now be considered overdoses for most, if not all, lakes. Hence, it would appear that the effects of toxaphene upon the bottom fauna are minor when it is used in the proper range for fish eradication.

HEALTH HAZARDS IN THE USE OF CHLORINATED INSECTICIDES

Judging from existing toxicity data, it does not appear that important hazards will arise from the addition of toxaphene to waters not used as drinking water supplies, in a quantity required for fish eradication. Even overdoses would not appear to be dangerous. Hemphill (1954) calculated that a cow would have to drink 18,000 gallons of water per day containing 100 parts per billion of toxaphene to receive a toxic dose. Since treatments will require less than 25 p.p.b. in most cases, it would seem that there is little chance that man would ever receive an acute dose (60 mg. per kg.). Toxicity data suggests that, as it is used in lake treatments, it is less hazardous than rotenone. Its toxicity to fish (96-hour TLm, Henderson and Pickering, 1958) is 4 parts per billion as compared to 11 parts per billion for rotenone. Thus toxaphene is nearly three times as toxic as rotenone and can be used in concentrations one-third as great. Comparable Oral LD₅₀ values for rats in mg. per kg. body weight are 90 for toxaphene as compared to 132 for rotenone (*ibid.*, 1958). Thus it would appear that rotenone is about 50 percent less toxic to

Table 2. Bottom Fauna at a Littoral Station in Little Squaw Lake, Marquette County, Michigan, Before and After Treatment with Toxaphene at 10 Parts Per Billion

(4 Ekman samples in each collection)

Number per one-quarter square foot	Before treatment (April 29, 1958)		After treatment (May 13, 1958)	
	Mean	Standard error	Mean	Standard error
Glyptotendipes sp.	45	5.5	35	3.4
Other diptera	6.7	1.9	6.5	1.5
Ephemeroptera	...	...	$\frac{1}{1}$	$\frac{1}{1}$
Trichoptera	...	...	$\frac{1}{1}$	$\frac{1}{1}$
Total weight (mg. per 1/4 ft. ²)	192	30	128	10

$\frac{1}{1}$ /Less than 1 per 1/4 ft. ²

mammals than toxaphene, but must be used in concentrations three times as great to kill fish.

Regulations on the usage of insecticides as fish poisons appear to differ from state to state. Although clearance for use of toxaphene in fish eradication has come from health agencies in Michigan and presumably in other midwestern states, authorities in certain states apparently do not favor its use in public waters even in the low concentrations required for fish eradication. Many difficulties experienced by aquatic biologists in obtaining clearance have arisen from conflicting statements made by federal public health officials. To avoid such incidents, it is suggested that a qualified federal health agency evaluate the hazards that might arise from the use by state agencies of toxaphene and other insecticides for fish eradication. Such an evaluation would be welcomed by state conservation agencies.

REFERENCES

Burdick, G. E., Howard J. Dean, and Earl J. Harris. 1955. Toxicity of emulsifiable rotenone to various species of fish. *N. Y. Fish and Game Jour.*, Vol. 2, pp. 36-67.

Catt, James. 1934. Copper sulfate in the elimination of coarse fish. *Trans. Am. Fish. Soc.*, Vol. 64 (1934), pp. 276-280.

Clemens, Howard P., and Mayo Martin. 1953. Effectiveness of rotenone in pond reclamation. *Trans. Am. Fish. Soc.*, Vol. 82 (1952), pp. 166-177.

Cushing, Colbert E., Jr., and John R. Olive. 1957. Effects of toxaphene and rotenone upon the macroscopic bottom

fauna of two northern Colorado reservoirs. *Trans. Am. Fish. Soc.*, Vol. 86 (1956), pp. 294-301.

Doudoroff, Peter, Max Katz, and Clarence M. Tarzwell. 1953. Toxicity of some organic insecticides to fish. *Sewage and Ind. Wastes*, Vol. 25, pp. 840-844.

Embody, Daniel R. 1940. A method of estimating the number of fish in a given section of a stream. *Trans. Am. Fish. Soc.*, Vol. 69 (1939), pp. 231-236.

Fukano, Kiyoshi G., and Frank F. Hooper. 1958. Toxaphene (Chlorinated Camphene) as a selected fish poison. *Prog. Fish-Cult.*, Vol. 20, pp. 189-190.

Hayes, Murray L. 1955. Evaluation of Ryania and Malathion as fish toxins. *Colo. Coop. Fish. Res. Unit, Quar. Rep.*, Vol. 1, Nos. 3 and 4, pp. 40-42.

Hemphill, Jack E. 1954. Toxaphene as a fish toxin. *Prog. Fish-Cult.*, Vol. 16, pp. 41-42.

Henderson, Crosswell, and Quentin H. Pickering. 1958. Toxicity of organic phosphorus insecticides to fish. *Trans. Am. Fish. Soc.*, Vol. 87 (1957), pp. 39-51.

Hooper, A. D., and J. M. Hester. 1955. A study of thirty-six streams that were polluted by agricultural insecticides in 1950. *Ala. Dept. Cons., Fish. Rep. No. 2*, 13 pp.

Hooper, Frank F., and Alfred R. Grzenda. 1957. The use of toxaphene as a fish poison. *Trans. Am. Fish. Soc.*, Vol. 85 (1955), pp. 180-190.

Lawrence, J. M. 1950. Toxicity of some new insecticides to several species of pondfish. *Prog. Fish-Cult.*, Vol. 12, pp. 141-146.

Rose, Earl. 1957. Preliminary tests of toxaphene in fish population control. *Iowa State Conserv. Comm., Fish and Game Div., Quar. Biol. Rep.*, Vol. 9, No. 4, pp. 4-6.

1958. Further notes on toxaphene in fish population control. *Iowa State Conserv. Comm., Fish and Game Div., Quar. Biol. Rep.*, Vol. 10, No. 2, pp. 5-7.

Stringer, George E., and Robert G. McMynn. 1958. Experiments with toxaphene as fish poison. *Canadian Fish. Cult.*, Issue 23, pp. 39-47.

Tanner, Howard A., and Murray L. Hayes. 1955. Evaluation of toxaphene as a fish poison. *Colo. Coop. Fish. Res. Unit, Quar. Rep.*, Vol. 1, Nos. 3 and 4, pp. 31-39.

Titcomb, John W. 1914. The use of copper sulphate for the destruction of obnoxious fishes in ponds and lakes. *Tans. Am. Fish. Soc.*, Vol. 44 (1914), pp. 20-26.

Wilkins, L. Price. 1955. Observations on the field use of cresol as a stream-survey method. *Prog. Fish-Cult.*, Vol. 17, pp. 85-86.

Young, L. A., and H. P. Nicholson. 1951. Stream pollution resulting from the use of organic insecticides. *Prog. Fish-Cult.*, Vol. 13, pp. 193-198.

BIOASSAY PROCEDURES, AIMS, AND EQUIPMENT

Discussion Leader

CROSWELL HENDERSON

U. S. Public Health Service

Robert A. Taft Sanitary Engineering Center

The meeting was opened by the discussion leader who explained the bioassay procedure which will be included in the eleventh edition of *Standard Methods*. This method is based primarily on that suggested by the Toxicity Subcommittee of the Federation of Sewage and Industrial Wastes Associations (Doudoroff, et al, 1951).

The method consists essentially of preparing a logarithmic series of test concentrations of effluent or chemical in a selected dilution water, adding the test fish, and observing their reactions, for definite time periods. Percent survival of fish is plotted against the log concentration of effluent on semi-logarithmic graph paper. Two points, the closest on each side of the 50 percent survival line are connected by a straight line. From the point at which this line intersects the 50 percent survival line, a perpendicular is drawn to the concentration axis. The point at which it intersects is the concentration which produces 50 percent mortality in the allotted time or the TLm value which is a direct measure of toxicity. Certain requirements such as temperature control, number and size of test fish, volume of test solution, and

maintenance of dissolved oxygen are built into the design of the bioassay.

While this method is not completely standardized, especially with respect to dilution water and species of fish, it gives a direct, replicable measure of toxicity of any mixed industrial effluent, pure chemical, or other toxicant. It can be adapted to obtain valid and directly applicable toxicity information in almost any pollutional situation. Standardization of methods of reporting results allows for a comparison of data by different investigators.

The facilities and equipment necessary for setting up a laboratory and conducting bioassays were described as were the many purposes for which bioassays could be used (Henderson and Tarzwell, 1957). The major factors to be considered in applying laboratory bioassay results to actual pollutional situations were also described (Henderson, 1956).

The meeting was then opened for discussion and a lively discussion ensued concerning the following major points:

Methods of computing results -

There was apparently some disagreement with the use of the TLm method of plotting and obtaining bioassay results. It was felt that more accuracy and data more amenable to statistical analysis could be obtained by other methods, such as probit analysis. Time-concentration relationships may also be more useful in many situations. It was pointed out, however, that with the variability in the toxicity of an industrial effluent and with the current uncertainty in application of bioassay results or determining safe concentrations that such increased accuracy would be of doubtful value in most pollutional situations.

Static vs. continuous flow bioassays -

The relative merits of static and continuous flow bioassays were discussed. Continuous flow bioassays would be definitely advantageous where volatile and high oxygen demand effluents were of concern. Bioassays could also be conducted for longer time periods with minimum changes in experimental conditions. Where chronic effects of an effluent were indicated, continuous flow bioassays would be necessary. It was agreed that more accurate information

could be obtained with continuous flow bioassays and that they should be used when possible. The difficulty in setting up this type bioassay and the extra equipment needed would be a drawback in some situations. Static bioassays, however, are adequate for many situations, especially for routine control testing of industrial effluents and for the tracing of toxic sources. An adequate bioassay laboratory should include provisions for both static and continuous flow bioassay.

Test fish -

Considerable discussion was held regarding the use of a standard fish for bioassays. It was agreed that a suitable species must be readily available in uniform size at all times and must be readily adaptable to laboratory conditions. It was pointed out that relative toxicity between species depended on the chemical of concern. A particular species may be more sensitive to one chemical and less sensitive to a different chemical than other species. Bioassays in any pollutional situation should be pointed towards the major species of concern. Most bioassays could be conducted on a good laboratory species but enough information would have to be developed to relate the data to important food and game species in the receiving water. It would be desirable, however, to have a reference species. The common guppy (*Lebistes reticulatus*) was suggested as a standard fish. It can be raised in the laboratory under uniform conditions, it can be selectively bred, it is of a convenient size, and is moderately sensitive to many toxicants.

Dilution water -

The possibility of the use of a standard water for conducting bioassays was discussed. It was pointed out that with many chemicals, toxicity varied greatly with changes in water quality characteristics. Information obtained with a standard water would not be applicable to specific situations. In pollutional situations, the dilution water should be that from the receiving stream or water with similar characteristics. The use of two waters, which would cover the range of most natural waters, was considered a reasonable approach for developing toxicity information on pure chemicals. Curves or mathematical relationships between

water quality characteristics and toxicity would be desirable.

Time -

It was generally agreed that the length of time that bioassays should be conducted depended on the purpose of the test. A comparison of results obtained from very short term tests with those from periods of longer exposure was generally considered to be at least partly responsible for the confused state of the toxicity literature. Forty-eight hours was considered a reasonable time for most bioassays. Shorter term tests would not give replicable information and longer time periods would produce changes in experimental conditions. However, if chronic conditions were indicated, longer term tests should be conducted, preferably under continuous flow conditions.

The general consensus of the group was that the bioassay method proposed was generally adequate for determining industrial waste toxicity in specific situations. It would also help considerably in the exchange of toxicity information between workers and would go far in helping to correct the present confused state of the toxicity literature. However, it was felt that there was a need for a more standardized method, including a standard water and a standard fish for developing information on the toxicity of chemicals. Such a method should be developed and also included in Standard Methods. The possibility of the use of a more precise method of computing bioassay results was also suggested.

Major effort in the future should be directed towards the development of reliable methods for estimating safe concentrations of chemicals or effluents under various conditions. Possibly some mathematical relationships or formulae could be developed. Toxicity information should be more closely related to physical and chemical information.

There is also a definite need for development of bioassay methodology for work with various life history stages of fish and fish food organisms. The physiological effects of various toxicants are also badly in need of investigation.

REFERENCES

Doudoroff, et al. 1951. Bioassay methods for the evaluation of acute toxicity of industrial wastes to fish. *Sew. and Ind. Wastes*, 23:(11) 1380-1397.

Henderson, C. and C.M. Tarzwell. 1957. Bioassays for control of industrial effluents. *Sew. and Ind. Wastes*, 29:(9) 1002-1017.

Henderson, C. 1956. Application factors to be applied to bioassays for the safe disposal of toxic wastes. *Trans. of Seminar on Biol. Prob. in Water Poll.*, R. A. Taft San. Engrg. Center, Cincinnati, Ohio, pp. 31-37.

**HOW SHOULD WE DETERMINE
DISSOLVED OXYGEN CRITERIA FOR
FRESH WATER FISHES?**

Discussion Leader

PETER DOUDOROFF

U. S. Public Health Service

Robert A. Taft Sanitary Engineering Center
Corvallis, Oregon, Field Station

Dissolved oxygen criteria or standards used in the regulation of waste disposal usually are simply minimum oxygen concentrations taken to be compatible with adequate protection of fish and other valuable aquatic life. The dissolved oxygen minima which have been regarded as appropriate criteria and adopted as such by regulatory agencies have differed widely. One major reason for the variety of standards is lack of agreement, among those responsible for the establishment of the criteria, as to the objectives to be achieved and as to the necessary degree of assurance that these ends can indeed be achieved through application of a given standard. Should the aim be unimpaired productivity of fish populations, or only the persistence of these populations at some, perhaps considerably reduced, levels of abundance and productivity? Should the standards adopted be oxygen concentrations at which damage to fish populations is almost inconceivable, or should they be concentration levels only slightly above those concentrations which are certainly detrimental?

It is obvious that agreement with regard to these fundamental questions must be reached before there can be very profitable consideration of specific concentration values to be selected, on the basis of available scientific data, as ap-

propriate criteria. Yet, it appears that there can be no such agreement even among biologists concerned with fish conservation and pollution control problems. Some have expressed the opinion that it is expedient to adopt initially standards which eventually may prove too low but would be readily accepted by industry, thus encouraging necessary cooperation of industry in the initiation of pollution abatement measures. They maintain that the standards can be raised when convincing evidence comes to light of the need for higher standards, the initial adoption of which is likely to be resisted by industry as being unnecessary and unrealistic. Others have pointed out that standards once adopted and used for some time tend to become fixed and are not easily raised, so that even tentative approval of inadequate standards sometimes can result in serious and perhaps irreparable damage to fish populations before appropriate adjustments can be made. There is also some difference of opinion as to the degree of impairment of fish production that might be reasonably accepted as an inevitable consequence of population growth and industrialization of an area, and of the use of public waters for waste disposal.

There can be no reasonable doubt that persistent low oxygen concentrations which are not rapidly lethal for fish can result in serious impairment or eventual destruction of fish populations. Marked effects of these reduced oxygen concentrations on the activity of fish and their ability to resist currents, on food consumption and growth, and on embryonic development, have been demonstrated experimentally. Evidence has been presented that certain physiological processes or functions (e.g., activity potential or work performance capacity, developmental rate, etc.) may be affected, in some degree, by any considerable reduction of dissolved oxygen below the air-saturation value. The incipient effects of oxygen reduction are not necessarily important or incompatible with good survival, normal growth, and general well-being of fish under both experimental and natural conditions. The view has been expressed, however, that it may be safely assumed that animals generally do not possess performance capabilities far in excess of those which sometimes are advantageous and necessary for self-preservation and continued success of the animals in nature. It has been suggested that some moderate degree of impairment of important functions of fish, such as a 20 percent reduction of the activity potential, might be taken to be an

acceptable basis for the determination of water quality criteria. However, any such decision admittedly must be arbitrary at this time, for an assumption that any particular, moderate reduction of work performance capacity, of developmental rate and the size of hatched larvae, etc., is nearly the maximum reduction which could not result in the eventual destruction or serious reduction of valuable fish populations would have no very sound, factual foundation.

A view which has been expressed is that minimum dissolved oxygen concentration standards need not be very far above those concentrations which are known to be more or less rapidly fatal for fish. It has been argued that average oxygen concentrations would be much higher, and therefore entirely adequate, in virtually all situations where waste disposal regulations based on such standards are rigidly enforced. One objection to this view is that dissolved oxygen concentrations in polluted waters do not always fluctuate rapidly and widely, and that refinement of waste disposal practices could in many instances result in the elimination of wide fluctuations of dissolved oxygen, permitting the maintenance of uniformly low concentrations near the prescribed minimum for long periods. Criteria based on the assumption that low oxygen concentrations will persist for short periods only thus can be misleading. Yet, the wide diurnal and other variations of dissolved oxygen in many natural and polluted waters perhaps should not be entirely disregarded. The adoption of dual criteria having to do with both short-term and prolonged or sustained depression of dissolved oxygen has been considered as one possible solution for the problem under consideration. To be more specific, an absolute minimum level below which oxygen concentrations should not fall at any time, and a higher level below which the concentrations should not remain for more than a certain number of hours (e.g., 8 hours) during any one day, have been proposed as appropriate criteria. It has been pointed out, however, that the enforcement of waste-disposal regulations based on such criteria would be very difficult and costly in many instances, and that there is virtually no specific information available concerning the chronic or long-term physiological effects on fish of fluctuations of oxygen concentration (i.e., repeated exposures for limited periods to non-lethal low concentrations), which could serve as a basis for such criteria. Experimental data bearing on this

problem certainly are needed.

It is apparent that any given standard cannot be equally appropriate or applicable to all situations, so that uniformity of standards applied in dealing with different waters in different localities is not necessarily a sound and desirable objective. Oxygen concentrations at which some fish populations can thrive may be highly detrimental to others; and concentrations which are not likely to be detrimental to fish in waters through which sensitive species must pass only occasionally and do not remain for long periods can be entirely inadequate for successful development and growth of sensitive resident forms and the young of migratory species elsewhere (e.g., in important spawning and nursery areas). Furthermore, it is well known that the dissolved oxygen requirements of fishes are markedly increased in the presence of various toxic pollutants, at unusually high temperatures, and so forth. Therefore, dissolved oxygen criteria suitable for waters which receive only non-toxic organic wastes and are not otherwise unusual may not be satisfactory for application to other waters, such as waters receiving a variety of toxic industrial wastes.

In the past, dissolved oxygen criteria have been based largely on field observations, such as the variety and relative abundance of fish and other desirable aquatic organisms in more or less polluted waters, as related to the recorded dissolved oxygen concentrations. It is evident that such observations alone do not constitute an entirely adequate basis for reliable dissolved oxygen criteria, inasmuch as dissolved oxygen concentration is not the only factor which may limit the variety and abundance of fish in waters receiving organic wastes. The blanketing of stream bottoms with bacterial and other growths (periphyton) which thrive in the presence of many organic wastes and may seriously affect the production of fish-food organisms and fish reproduction, the injurious effects of toxicants associated with the organic wastes, and other factors may be equally or more important in many instances. Furthermore, the past history, with respect to dissolved oxygen, etc., of the aquatic environments whose biotas have been investigated in seeking to arrive at water quality criteria usually is not well known. Real understanding of the dissolved oxygen requirements of aquatic life evidently must be achieved largely through carefully controlled experiments.

Another general conclusion which seems unavoidable is that the determination of dissolved oxygen and other water quality standards is an administrative problem, and not a purely scientific one. These standards must necessarily be based not only on scientific data, but also on a variety of other considerations, economic, sociological, legal, political, etc. It should not, therefore, be a duty of the biologist engaged in research in the water quality requirements of aquatic life to establish water quality criteria for use by regulatory agencies. What the biologist can be reasonably called upon to do is to render scientific judgement with regard to the probable biological consequences of any proposed alteration of a particular aquatic environment. It is for administrators to decide what consequences are to be admitted or hazarded, then to choose their criteria accordingly, and to decide just how widely and in what manner these are to be applied.

THE PROBLEM OF NUISANCE GROWTHS DUE TO ORGANIC ENRICHMENT

Discussion Leader

H. HEUKELEKIAN
Department of Sanitation
Rutgers University
New Brunswick, New Jersey

Although a variety of fungi, algae, and bacteria are potential contributors to nuisance growths, or as organisms which may appear in isolated instances, *Sphaerotilus* is often of economic and ecologic importance because of its frequent occurrence and massive growth in streams enriched organically, especially in those receiving wastes rich in soluble, readily available organic materials, e.g. sulfite liquor, beet processing wastes, distillery wastes, etc.

Among those mentioned as occasional nuisance organisms are *Saprolegnia*, *Acetobacter*, *Penicillium*, *Achyla*, *Zooglea*, *Leptomit*, and *Fusarium*. The types of nuisance organisms are determined, to a great extent, by the following factors: (1) aeration, (2) pH, (3) salinity, (4) flow or circulation of the water, and (5) type of pollution nutrients.

The bacterial growths occur more frequently in streams, or other flowing water, than in lakes, although a heavy growth was noted in a bay of the Great Lakes where there was circulation of the water.

The habit of attachment adapts *Sphaerotilus* to growth in flowing water where the level of organic enrichment can be very low, e.g. 1 p.p.m. or less of BOD, because the nutrients are constantly renewed by the passage of the water. *Sphaerotilus* appears in objectionable quantities only when organic pollution enters the stream. Simple sugars, organic acids, alcohols, distillery wastes, sewage, and sulfite liquor encourage the growth of nuisance quantities of *Sphaerotilus*. It has also been seen growing luxuriantly on log rafts. The capacity of the organisms to grow at low levels of dissolved oxygen is shown by its presence in polluted streams in the absence of detectable dissolved oxygen; it is not anaerobic, however, so that growth in the apparent absence of oxygen is limited to situations where reaeration is possible, i.e. near the surface or in riffles.

Apart from unsightliness, the major objections to infestations are interference with fishing and deterioration of the environment for fish. The detached *Sphaerotilus* fills the nets of commercial fishermen and fouls the lines and lures of anglers. Upon detachment of the attached growth, the floating blossoms are carried downstream and are ultimately deposited creating adverse habitat for fish by blanketing the bottom.

Sphaerotilus can be readily isolated and maintained in the laboratory on artificial culture media, both complex and synthetic. It appears to exhibit much the same characteristics in artificial culture media as in the stream. A capsule is often present, surrounding a tubular, cylindrical sheath which contains the ellipsoidal to cylindrical cellular units. The cells may often be found outside the sheath and are often motile.

The sheath has been separated from the cells by homogenization, treatment with sodium lauryl sulfate to lyse the cells, and washing by centrifugation. On hydrolysis the sheath was found to contain reducing sugars.

In the isolation of *Sphaerotilus* colonies, they should be distinguished from some strains of

Bacillus which exhibit somewhat similar characteristics, that is the ability to grow in cohesive linear strands because of the presence of a tough cell envelope which, on autolysis of the cells, remains as a "pseudosheath". When true sheaths are absent, when septa or spores are present, the organism is not Sphaerotilus, but a Bacillus.

**THE SIGNIFICANCE OF PERIPHYTON
ON NATURAL AND ARTIFICIAL
SUBSTRATES**

Discussion Leader

GEORGE H. LAUFF
Department of Zoology
University of Michigan
Ann Arbor, Michigan

The term "periphyton" was introduced to designate the assemblage of organisms associated with submerged artificial substrates, though in American usage the term is frequently restricted to the organisms attached to stems of higher aquatic plants. Within recent years the German "Aufwuchs" has been used as the equivalent of "periphyton", though the former term has a broader connotation, and includes sessile organisms as well as various free-living forms inhabiting the matrix formed by the attached biota. For the purposes of this discussion, periphyton is defined as the assemblage of organisms growing on free surfaces of submerged objects and covering them with a slimy coat.

The role of periphyton in the aquatic habitat is that of a production assemblage similar to the plankton and benthic communities. Insofar as the periphyton may contain many typically free-living bottom animals, there is a tendency to regard it as part of the benthos; it may contain common planktonic forms as well, however.

In the lentic environment, the periphyton is predominantly associated with the rooted aquatic plants, and the organic matter that is produced by the epiphytic biota may be contributed to the plankton and/or benthos communities through the grazing and predatory activities of their component organisms. Undoubtedly it also makes a direct contribution to the nekton owing to the browsing of fish.

The importance of the periphyton in the trophic relationships in lakes has not been expressed in quantitative terms, though it has been commonly observed that lakes with a scanty growth of higher aquatic plants are generally low in yield of invertebrates and fish. Gerking (1957) has presented a method of sampling the littoral macrofauna which differentiates the bottom dwelling animals, or benthos, from the organisms living in association with the plants, or phytomacrofauna. Results indicated that the phytomacrofauna consisted of forms which were almost wholly lacking in the benthos but were commonly associated with plants. The quantity of phytomacrofauna increased as the quantity of plants increased, with the greatest faunal increase being found on the plant species having the greatest leaf area. Since the macrofaunal species which mine the various parts of the plants were not considered, the greatest potential contribution of phytomacrofauna to the trophic relations of the lake would seemingly be made by plants with the greatest surface area. The significance of periphyton in determining the abundance of phytomacrofauna was not considered, but it would be logical to assume that periphyton would increase in proportion to plant surface area and thus contribute directly to the production of the faunal assemblage associated with the plants. More detailed knowledge of the feeding habits of the components of the phytomacrofauna would permit a better assessment of the specific contribution of both periphyton and the higher aquatic plants in phytomacrofauna production.

Recent observations in chemical weed control programs in which arsenite poisons are employed suggest that the periphyton may assist in the penetration of the chemical. Plants collapse after arsenite treatment and it has been noted that the most significant damage to the plant stems occurred where the periphyton growth was most abundant.

Periphyton in lotic habitats is commonly found on stones, rubble, and other submerged objects. In streams, the role of periphyton as a productive assemblage is particularly important since physical characteristics of the stream may prevent the development of a potamoplankton community. In addition to its significance as a production assemblage, the periphyton in streams, together with the mosses and higher aquatics, acts as a physical screen, trapping the particular material carried by the water current and removing it from suspension.

Periphyton can influence the distribution of stream macrofauna directly by providing a habitat and a source of food for benthic organisms, but it also can exert profound influence on substrate characteristics by slowing the current velocity, resulting in the deposition of the finer materials. The physical relations between current velocity, sedimentation, and substrate particle size have great biological significance, though they are not fully appreciated by biologists. The basic considerations have been presented by Inman (1949) and have been applied to animal-sediment relationships in the marine environment by Sanders (1956, 1958).

In the lotic habitat, periphyton growths result in a reduction in current velocity in the vicinity of the surfaces on which they are growing owing to simple frictional forces. With a reduction in current velocity, finer particles which would have otherwise remained in suspension may be deposited. The deposited materials, together with the periphyton growth on other associated substrates, presents a relatively more smooth hydrodynamic surface with a result that higher current velocities must be achieved to induce movement and resuspension of the settled particles. In the absence of increased current velocities, continued sedimentation can cause a "silting-in" of areas, and may eventually eliminate the periphyton. In this instance, the altered food chain would promote faunal succession from a community based on algal feeders to one based on detrital feeders.

The present knowledge of periphyton growth on artificial substrates is based chiefly on attempts to obtain representative qualitative and quantitative samples in order to follow population growth and succession. Artificial substrates are also commonly employed in obtaining materials for morphological and physiological investigations in phycology, mycology, and protozoology. A recent review of methodology related to the algae has been presented by Lund and Talling (1957).

Glass and/or plastic slides have been utilized in making estimates of stream productivity, and in the isolation and enumeration of algal species for evaluation of pollution. By the use of artificial substrates, conditions affecting the productivity of a stream may be detected from differences in the character of the biota

Changes in the qualitative and quantitative relationships of the periphyton complex, when contrasted with those of the normal flora, are interpreted to indicate organic enrichment or toxicity when they can be distinguished from seasonal succession and non-random distribution.

Owing to difficulty in studying periphyton on naturally occurring substrates like rocks and aquatic plants, many artificial surfaces have been used for sampling periphyton: glass slides (smooth and etched), plexiglass (smooth and roughened), styrofoam, sterilized rocks, rocks ground smooth, clean surfaces of higher aquatic plants, unglazed porcelain, wooden blocks, and transite. Although etched glass slides may offer better attachment surfaces for periphyton and protozoans, smooth plexiglass was found to be more suitable than roughened. In silty or fast flowing waters, styrofoam may be more suitable than glass slides for attachment of diatoms because of the rough surfaces. The closed cellular structure of a piece of styrofoam allows a clean, fresh surface to be exposed by simply slicing off the old surface.

Rocks, ground smooth, have been used as a more convenient form of natural substrate for quantitative assay, but organisms are retained in the pits in the surface. The collodin technique for stripping off cells from rock for quantitative transfer to a microscope slide may be employed as a supplementary method for examining rock surfaces.

The degree to which artificial substrates give an accurate picture of the qualitative and quantitative characteristics of the periphyton in a particular aquatic environment is not well known. Since many of the substrates employed are not chemically inert, the question of selectivity and tolerance arises. Often times the biota noted to be abundant on the introduced substrates is not commonly found in nature. It has been suggested that artificial substrates may be selective in that primary colonizers, perhaps actually non-selective, modify the substrate through secretions or their own presence. Bacteria have been found to colonize sterilized rocks before algae become attached, but it is not so for other periphyton organisms. Similarly, diatoms secrete a jelly and attach to slides, though dead cells will fall off.

Because of the number of factors affecting the collection of periphyton on artificial sub-

strates, methods used for assaying the community should be tested for reliability. The length of time of immersion appears to be of prime consideration since it relates to probable community secession and the browsing activities of other components of the biota. It has been noted that increased periods of immersion tend to reduce the differences between artificial and natural substrates. Depth of immersion, orientation to light and current, temperature, and season are also important.

REFERENCES

- Gerking, S.D. 1957. A method of sampling the littoral macrofauna and its application. *Ecol.*, 38:(2)219-226.
- Inman, D.I. 1949. Sorting of sediments in the light of fluid mechanics. *J. Sed. Pet.*, 19:(2)51-70.
- Lund, J.W.G. and J.F. Talling. 1957. Botanical limnological methods with special reference to the algae. *Bot. Rev.* 23:(8-9)489-583.
- Sanders, H.L. 1956. Oceanography of Long Island Sound, 1952-54. X. Biology of marine bottom communities. *Bull. Bingham Oceanogr. Coll.* 15:345-414.
- _____. 1958. Benthic studies of Buzzards Bay. I. Animal-sediment relationships. *Limnol. and Oceanogr.* 3:(3)245-258.

THE PULP AND PAPER MILL WASTE PROBLEM

Discussion Leader

HAYSE H. BLACK
U. S. Public Health Service
Robert A. Taft Sanitary
Engineering Center

Lockwoods Directory of the Paper and Allied Trades - 1959, reports 76 sulphate (kraft) pulp mills in the United States operating in 23 states. Statistical data for the year 1956 indicate a production of 12,130,811 tons. Fifty five percent of the pulp produced was manufactured by the kraft process. Practically any kind of wood can be used, but coniferous woods predominate. The process was developed especially to remove the large amounts of oils and resins in these woods. Yellow pine constitutes about 40% of the wood used; tamarack, spruce, hemlock, balsam, jack pine, and white pine make up the remainder of the total.

The chemical reactions are rather indefinite but involve hydrolysis of the lignins to alcohols and acids. This hydrolysis also produces mercaptan and sulfides which are largely responsible for the familiar odor of sulphate pulp mills. The cooking liquor contains essentially sodium sulfide and caustic soda.

The kraft process provides recovery of chemicals by evaporation and combustion of the spent cook liquor (black liquor). Economics in a highly competitive industry dictate efficient recovery of chemicals and modern mills are reported to recover 85% to 95% of the sodium charged to the digester. Organic matter dissolved from the wood makes up 55% to 70% of the total solids in black liquor. Weak black liquor, as it is recovered from the washers, generally has 15% to 17% total solids and amounts to about 1700 gallons per ton of air dry pulp. It contains from 2100 to 2600 lbs. of solids per ton of pulp.

The 5-day biochemical oxygen demand discharged from a modern unbleached kraft mill amounts to approximately 50 pounds per ton of product. It has been reported possible to reduce suspended solids to 0.5% of production but usually losses are much greater, ranging between 1% and 2% of production.

In 1947, Van Horn, Anderson, and Katz, working at The Institute of Paper Chemistry, made a study of the toxic substances which may be found in kraft mill effluents. They reported that sulfides, mercaptans, resin acid soaps and sodium hydroxide constituted the greatest hazard. These research workers established the following minimum lethal concentrations of these materials to minnows:

(1) Sodium Hydroxide	100 p. p. m.
(2) Sulfide	1.2 p. p. m.
(3) Methyl Mercaptan	0.5 p. p. m.
(4) Resin Acid Soap	1.0 p. p. m.

Weyerhaeuser Timber Company used a Bergstrom Tower to remove toxic compounds from the effluent of their kraft pulp and paperboard mill at Springfield, Oregon, which mill discharges to the McKenzie River, a clean fishing stream. The contaminated water which is treated in this Bergstrom Tower stripping column comes from three sources in the kraft mill, namely: evaporator condensate; blow steam condensate from the accumulator; and

digester top relief condensate which has first been run through a turpentine decanter. Maximum and average concentrations of these toxic components in the effluent from this mill were reported as:

	<u>Maximum</u>	<u>Average</u>
Sulfides (p. p. m.)	0.5	0.07
Mercaptans (p. p. m.)	5.8	4.29
Resin acids (p. p. m.)	18.0	4.66

Description of this Bergstrom Tower for removal of effluent toxic compounds and the above data are given in a technical article by D. E. Allen, Weyerhaeuser Project Chemist, in the magazine PULP AND PAPER, Volume 25, February 1951, pages 56, 58, and 59.

The discussion was focused on the pollutional effect of these residual kraft mill wastes with emphasis being placed on their toxic characteristics. The distress and mortality of fish and invertebrate animals in diluted kraft mill wastes with dissolved oxygen concentrations believed to be well above the minimum requirements of the organisms have been observed repeatedly in the laboratory and in the field. However, there is a lack of agreement on the degree and importance of the toxicity of kraft wastes, as well as the constituents to which this toxicity is referable. The apparent discrepancies of published observations and conclusions are not surprising when we consider the complex nature of the wastes, variations in kraft mill design, equipment and operation, woods pulped, sources and kinds of wastes tested biologically, and toxicity evaluation procedures.

A number of investigators have evaluated the toxicity to fish and to other aquatic animals of some of the known constituents of kraft mill wastes. Unfortunately, definite conclusions relative to the toxicity of the complex wastes themselves have, too frequently, been based entirely on the results of these toxic evaluations and the chemically determined concentrations of the individually tested components. This procedure has two basic assumptions, namely: (1) that all of the important toxic constituents of kraft mill wastes are known and are accurately measurable by the chemical tests employed, and (2), that there is no interaction of the various components of kraft mill wastes such that the toxicity of the mixture could be markedly influenced by the concentra-

tions of the several components. Neither of these assumptions has been proven valid. It is well known that the combined effects on aquatic animals of mixed chemicals are often very different from those which would be predicated on the basis of information concerning the toxicities of the individual components.

The toxicity of kraft pulp mill wastes has been attributed to sulfur compounds, including inorganic sulfides and methylmercaptan, and to the resin acids or their soaps. These substances have been found in considerable amounts in kraft mill wastes and they have been shown to be toxic to aquatic organisms. Some correlation between the concentrations of these substances and the toxicity of kraft wastes has been noted. It has not been demonstrated, however, that the degree of toxicity of kraft mill wastes can be reliably predicated through evaluation of the concentrations and toxicity of any one or all of these components. Unpublished observations in the Pacific Northwest indicate that ether soluble materials from certain condensates resulting from evaporation of the black liquor are highly toxic.

In considering the toxicity of kraft pulp and paper mill wastes, attention must be given not only to natural components of the waste but also to materials added for foam control, slime control, coloring agents, bleaching, sizing, and fillers. Disinfectants used for slime control in paper manufacture may be expected to appear in the mill effluent. Toxicity studies have been made of slime control agents. This problem is complicated by the intermittent, high concentrations of the disinfectants employed.

Dr. Doudoroff discussed at some length the cooperative research in which he is engaged at Corvallis, Oregon. The physical, chemical, and toxicological properties, sources, interactions, and relative importance of different constituents of kraft pulp mill wastes, which are toxic to fish, are being investigated. Attempt is being made to isolate and to identify some of the unknown toxic compounds. Dr. Doudoroff referred to his work with "artificial streams" for studying responses of various stream organisms to environmental changes caused by introduction of pulp mill wastes. He indicated that nuisance slime growths on the stream bottom could reduce oxygen levels sufficiently to inhibit growth of insects upon which fish feed.

Dr. Galtsoff reported that the effluent from large kraft mills on the York River were found to be nontoxic. He indicated efficient recovery and only occasional irregularities in operation. Some of these irregular waste discharges have been observed to occur during the night. It was brought out that the Vancouver Island kraft mill effluent did not deleteriously affect the oyster beds.

Dr. Heukelekian commented on the effects on the mill effluent of processing various types of wood. He inquired regarding evaluation of stabilization ponds in the treatment of kraft mill effluents. The Valdosta, Georgia installation of National Container Corporation was cited as one successful installation. Dr. Heukelekian referred to the use of oxidation chambers and stack gases to oxidize mercaptans as reported earlier for the Weyerhaeuser Timber Company, Springfield, Oregon pulp mill.

There was some discussion on sphaerotilus growths and causes. Dr. Heukelekian pointed out that trace concentrations of nutrients would support sphaerotilus growth. Therefore, to completely eliminate this growth would virtually mean 100% removal of nutrients. It was agreed that a reduction in nutrients would result in a corresponding reduction in slime growth.

Some published material indicates that if the receiving stream provides sufficient dilution to prevent critical oxygen depletion, there should be ample dilution to also prevent damage to aquatic life by toxic constituents. There was no unanimity of opinion on this subject.

Composition of Sulfite Waste Liquor

E. F. ELDRIDGE
U. S. Public Health Service
Portland, Oregon

The spent liquors from the sulfite pulping processes, commonly known as sulfite waste liquor (SWL), varies in composition over a considerable range depending upon the type of wood used and the grade of pulp manufactured. Generally it is found that this liquor will have a composition within the range of values given below.

The type of pulp produced is a major factor influencing the composition since it governs the

amount of non-cellulose material removed during the process and the amount of chemical used. For the purpose of this discussion, three grades of pulp will be considered; namely, paper pulp, dissolving or rayon pulp and high dissolving or tire-cord rayon pulp. The final product may be unbleached or bleached. Since the first part of the discussion is not concerned with bleach process wastes, the data given are for the pulping process only.

The following tabulation indicates the average yields of pulp and the percent of the weight of the wood contained in the waste liquors. (These values are based on dry weight).

	<u>In Pulp</u>	<u>In Waste</u>
Paper grade	45%	55%
Dissolving grade	40%	60%
High dissolving grade	37%	63%

This means that for every ton of pulp (dry weight) the weight of the solids in the waste from the process will be:

Paper grade	2440 pounds
Dissolving grade	3000 pounds
High dissolving grade	3400 pounds

Most of these solids, together with the chemicals used in the process, are contained in the sulfite waste liquor.

The chemical used is composed of a base, either calcium, magnesium or ammonium combined with sulfur dioxide. For the most part the chemical is a sulfite of one of the above bases. The weight of the chemicals used varies from 8 to 10 percent of the dry weight of the wood chips. For the calcium base cook the weight of chemical per ton of pulp produced is therefore about 450 pounds. Most of this will be contained in the waste liquor but will be altered by the reaction with the wood solids.

The solids content of the waste liquor as it is drawn from the digesters (the vessels in which the wood is cooked with the chemical) varies from as low as 6 to 16 or 20 percent. In order to standardize the reporting of analytical results and to assure a common basis of discussion, SWL is considered to contain 10% solids by weight. The results of analyses are converted to 10% liquor.

If sulfite waste liquor is discharged to a natural body of water it exhibits a high demand for oxygen. A part of this demand is the result of the chemical reaction between oxygen and the reduced sulfur compounds in the liquor, mostly sulfur dioxide. This is known as the "immediate oxygen demand" and makes up about 11% of the total (5-day) demand. The remaining demand is due to biological activity and is known as the biochemical oxygen demand (BOD). The amount of oxygen used by the waste in a period of 5 days is known as the 5-day BOD which is the usual way of reporting BOD results. The results are herein reported in terms of the pounds of oxygen needed to oxidize the SWL from every ton of pulp produced. Since the composition varies, the BOD also varies and is reported as a range of values below. The 5-day BOD of the waste liquor on this basis is:

	<u>Pounds per ton</u>
Paper grade	670 to 700
Dissolving grade	750 to 800
High dissolving grade	800 to 833

Another way of reporting the BOD of the waste is to compare it with the BOD of domestic sewage on a population equivalent basis. The average BOD of sewage has been found to be about 0.17 pounds per capita per day. On this basis the population equivalents of the SWL given above are:

	<u>PE per ton of pulp</u>
Paper grade	3950 to 4120
Dissolving grade	4410 to 4700
High dissolving grade	4700 to 4900

Sulfite waste liquors have been analyzed by a number of investigators. The following tabulation shows the results of a partial breakdown into components. (Results are given in percent of total solids).

Formic acid	0.5 to 0.8 per cent
Acetic acid	3.8 to 4.0 per cent
Methyl alcohol	0.5 to 1.0 per cent
Ethyl alcohol	0.14 to 0.17 per cent
Acetone	0.07 to 0.11 per cent
Furfural	0.18 to 0.24 per cent
Pentose	2.16 to 2.43 per cent

Hexose	12.3 to 14.8 per cent
Lignin	50.2 to 52.2 per cent
Misc.	24.8 to 29.5 per cent
Calcium	4.5 per cent
Sulfur	9.15 per cent

Over half of the solids in the liquor are lignins. These are relatively inactive compounds which break down slowly in natural waters. The sugars (hexoses and pentoses) are responsible for the major part of the BOD (about 63 percent). Calcium and sulfur compounds make up a considerable portion of the item listed as miscellaneous.

The waste liquor is very acid. The volume of sulfite waste liquor, (10%) varies from 2500 to 3000 gallons per ton depending upon the method of drawing from the digester. It is mixed with wash water before it is discharged from the pulp mill. The average mill uses about 60,000 gallons per ton of pulp. On this basis the 5-day BOD of the wastes from the various grades (not including that of bleaching or the hydraulic barker) is:

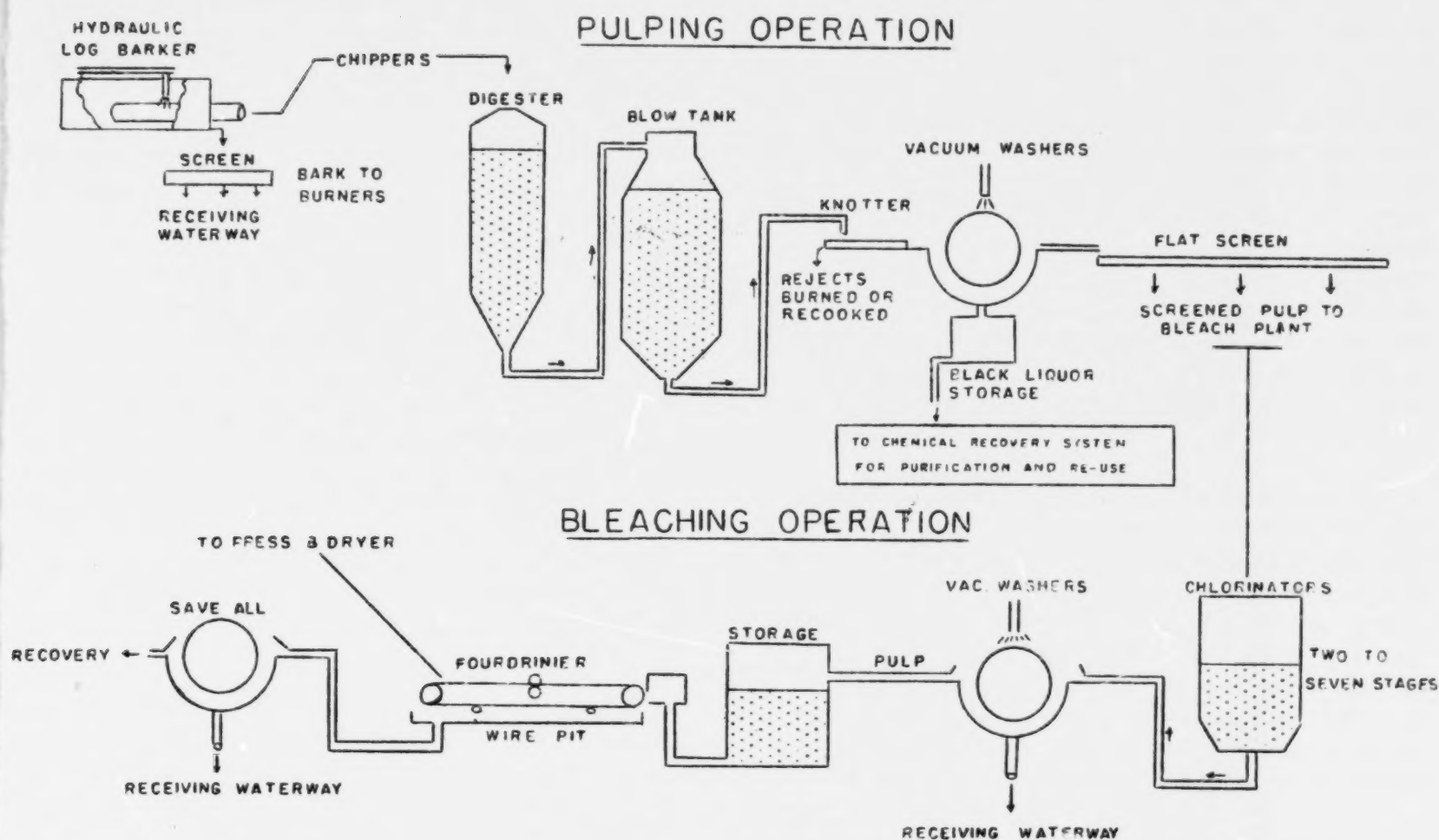
	<u>p. p. m.</u>
Paper grade	1340 to 1400
Dissolving grade	1500 to 1600
High dissolving grade	1600 to 1670

Thus the BOD of the total mill waste even after the very substantial dilution is over 10 times as great as domestic sewage before treatment.

Bleaching

Bleaching adds substantially to the BOD of the pulp mill although the quantity of bleach washings is high. This is especially true of dissolving - pulp operations where a highly refined product is necessary. If bleaching is a part of the operation the following BOD values in pounds per ton should be added to those given above.

	<u>Pounds BOD per ton</u>
Paper grade	29 to 37
Dissolving grade	126 to 130
High dissolving grade	169 to 210



Kraft Pulping Process - Flow Sheet

THE CONVERSION OF SPENT SULFITE LIQUOR INTO USEFUL PRODUCTS

Discussion Leader

BERNARD F. LUECK
Sulphite Pulp Manufacturers'
Research League
Appleton, Wisconsin

In November 1867, the first U.S. patent relating to the sulphite process was granted to Benjamin Chew Tilghman. Since then, hundreds of patents have been granted and a large industry has grown for the production of cellulose fiber by the acid cooking process. The wood, as it goes to the digesters, contains roughly 50% of cellulose fiber which means there remains 50% of unwanted material from the pulp makers viewpoint. In those early days, disposal of this half of the tree was no problem. Production

was low, population generally sparse, so consequently this material usually sewered by the shortest route to the nearest river or other body of dilution water, which in most cases had ample self-purification capacity.

All wood is composed primarily of cellulose, hemi-cellulose and lignin. In the natural state, these compounds are insoluble. However, in the acid cooking process some of the hemi-celluloses and most of the lignin is made soluble and thus separated from the desired cellulose. The lignin is converted to calcium lignosulfonate when calcium base cooking liquor is used and the hemicelluloses are broken down to sugars, etc. Depending upon the type of wood and degree of cooking, these sugars can constitute up to 20% of the solids in the spent sulphite liquor. The sugars which are readily attacked by micro-organisms in receiving streams are the principal source of the biochemical oxygen demand of the liquor.

Over the years countless researchers have struggled with the problem, both from the viewpoint of outright disposal and also from utilization. The Sulphite Pulp Manufacturers' Research League was organized in Wisconsin nineteen years ago as a cooperative research venture by Wisconsin sulphite mills. Since then, it has expanded its membership from coast to coast covering about 45% of the sulphite tonnage in this country. Its first efforts were directed primarily toward disposal techniques, but over the ensuing years this attack of the problem has been minimized in favor of the more logical economical probabilities of utilization.

The scope of the problem can be better visualized when we consider that the sulphite production in the United States results in the annual production of 3 million tons of spent sulphite liquor solids. While the sugars are primarily the first concern for the reduction of B.O.D., the hard facts of economics make it imperative that the whole or greatest portion of the total organic and inorganic solids be utilized or converted into useful products.

Although we are discussing what generally is considered a waste product, it must be understood that the so called waste is not cheap. Most sulphite mills in this country are what is generally classified today as small in size, averaging 100 to 150 tons of pulp production per day. For the most part they were built in the days when the most economical recovery of the fibers was the first concern with the result that washing systems are so constructed that the liquor solids can be obtained only in a very dilute state. Many mills find it difficult to obtain solids concentration higher than 6%. By rebuilding blow-pit and pipelines and by installation of new washing systems, concentrations of 10% to 15% are now obtainable. Cost of transportation of any product containing 85% to 90% water limits shipment to a radius of 100 miles. Generally utilization requires concentrations to 55% or 60% solids or to a dry powder which again is costly. The low acidity of the liquor necessitates that all evaporators be constructed of a high grade stainless steel resulting in a capital expenditure of around \$1,000,000,000 for evaporation.

Since the sugars in the spent sulphite liquor are readily attacked by microorganisms it was only natural that fermentation studies were

inaugurated at an early date as a means of obtaining a salable byproduct. The literature is saturated with descriptions of various types of fermentations yielding such products as ethyl alcohol, acetic acid, lactic acid, acetone, etc. and edible protein material. Of these only the production of ethyl alcohol and edible protein have attained significance. Large scale production of ethyl alcohol is practiced in Europe, where in many countries blending of alcohol into motor fuel is required by law. However, in this country the large capital expenditure for a fermentation plant and the synthetic production of alcohols and solvents from petroleum rules against new construction for alcohol fermentation of spent sulphite liquor. At the present time there is one plant on the west coast and two in Canada producing alcohol. These plants, however, were built under the war economy and were largely government subsidized.

During the closing months of World War II, Germany was building and placing in operation fermentation plants for the production of protein material which was to be used as a supplement to feed the German people. These plants were utilizing the sugars in the spent sulphite liquor as the media for the growth of "*torulopsis utilis*", a so called wild yeast. About the same time, and continuing for several years thereafter, the Sulphite League in Wisconsin conducted active research on this same type of fermentation. This research resulted in the eventual construction of two commercial plants for the production of yeast protein, which have been successfully operating at capacity for several years. Originally the entire production went to the feed industry, but the last several years have seen more and more utilized as human food supplements. Yeast production has several advantages over alcohol fermentation. The product is easier to recover and the organism used utilizes not only the hexose sugars, but the pentoses as well, while the alcohol producing organism can grow only on the hexoses. This becomes increasingly important as the availability of pulpwood supplies changes over from softwoods, with consequent predominance of pentose sugars in the S. S. L. produced from hardwoods.

Basically the yeast process is a simple one. The liquor, containing about 10% solids, is steam stripped for the removal of SO_2 and this acid gas is re-used in the pulping process. The treated liquor is then fed continuously to 45,000 gallon

open fermenters together with addition of ammonia, phosphorus and potassium nutrients which are lacking in the liquor. The ammonia may contribute also toward control of the degree of acidity at levels in which the torula yeast grows well, but other microorganisms do not. The entire mass is agitated and aerated by a Waldhof-type aeration wheel, which maintains an emulsion of about one part air to one of liquid. Temperature is maintained at around 84°F by pumping through an external heat-exchanger. After a holding time of from 3 to 4 hours, the yeast cells are centrifuged from the wort. Approximately 1/2 lb. of dry yeast is produced from each pound of sugar. After the initial centrifuging stage, the yeast is washed with water and further concentrated in succeeding stages of centrifuging. The 12 to 20% cream is then dried on drum driers.

Once the fermentation has been started, growth can be maintained continuously for months and years. If a lengthy shut-down is required the centrifuged cells can be maintained in a live state by simple refrigeration. The success of the process is due to the relatively short holding time required and the attainment of a continuous fermentation, rather than a batch process. The yeast produced contains about 50% protein and is rich in vitamins. About 90% of the sugars are removed from the original liquor. The B.O.D. reduction is less than indicated by sugar reduction and is usually about 65% due to the presence of non-sugar substances which contribute to the 5-day B.O.D. but which are not converted by yeast growth.

A process for reactive solvent extraction for the separation of the sugars from the liquor has been under development by the League for several years. Acetone soluble sugar derivatives are formed in reaction with a portion of the solvent and these derivatives can then be separated from the acetone-insoluble residue. A wide range of operating conditions is possible to yield a variety of up-graded end products from both the lignin and sugar portions. The individual sugars can be separated by taking advantage of differences in their properties.

So far we have been discussing primarily the sugar portion of the spent sulphite liquor. Although lignin and lignosulfonic acids have been studied by researchers for nearly a full century, the structure of lignosulfonic acid is still poorly understood. It is a mixture of polymers having

different degrees of sulfonation and a molecular weight range of 1000 to more than 20,000. Some of these macromolecular substances may range to 300,000 M.W.

In Europe where fuel costs are high, the spent sulphite liquor solids are burned for their heat value. This practice is followed to a limited extent in this country, but only for disposal of the liquor, as cheap fuels make it economically unsound. Before burning, it is necessary to concentrate the liquor to a syrup before it will support combustion. Previous to the introduction of the Swedish Rosenblad evaporator, concentration of the calcium base liquor presented serious scaling problems. The general practice is to evaporate the digester strength liquor (10% to 15%) to 55% to 65% concentration and then burn it in specially equipped boilers, either alone or in conjunction with oil or coal.

The Zimmerman process which destroys organics for heat recovery by a wet oxidation under high pressures has been advocated as a means of utilization and disposal. Claims are made for the recovery of inorganics as well as heat. As yet it has not been proven on a commercial scale although there is a plant nearing completion in Norway. Again the desire for better utilization of these organics and the availability of cheap fuels in this country may combine to swing the economic pendulum away from the process.

In 1958, about 26,650 tons of spent sulphite liquor solids were used to treat secondary roads in Wisconsin. Most of this was sprinkled on gravel surfaced roads as a dust preventative, with and without mechanical mixing of the binder with the soil. Definite procedures have been worked out for its application. It has also shown promise as a stabilizer for base courses prior to covering with a bituminous or concrete wearing mat.

The Howard Process was one of the early successful procedures for obtaining the lignosulfonates by precipitation methods in a usable form free of sugars from calcium base liquors. It consists of a three stage lime precipitation of the nonsugar solids. The calcium sulfite from the first stage is used in preparing fresh cooking acid. The effluent contains sugar decomposition products.

Vanillin is being produced by four mills in this country and Canada by alkaline oxidation of

softwood lignosulfonates at elevated temperatures and pressures. The starting materials are desugared lignosulfonates.

Other uses for either the whole or modified liquor are as adhesives; binders for briquettes; in cements for hardening and improving its durability and lowering the set time; in ceramics; as dispersing agents in emulsions; as resin extenders in plastics; and as fillers for use in conjunction with vegetable tanning agents.

Over the years the successful use of the lignosulfonates has always run into the economic barrier that other products can do the job cheaper or better. Accelerated research continues and as more is learned of the lignin molecule and new ways are discovered to fractionate the various lignosulfonates, means will be found to take advantage of its favorable properties. In the meantime, millions of pounds of what some day will probably be a valuable raw material are still going to waste.

REFERENCES

- Lewis, Harry F. 1945. Lignin - An Economic Liability or a Chemical Asset. *Chem. Eng. News*, 23:1074-1080.
- Whitmore, L. M. and Wiley, A. J. 1958. Chemical By-Products from Spent Sulphite Liquors. *Chem. Eng. Progress*, 54(12):80a-80d.

EFFECTIVE METHODS FOR COLLECTING AND RECORDING DATA FROM WATER POLLUTION SURVEYS

Discussion Leader

W. M. INGRAM

U. S. Public Health Service
Robert A. Taft Sanitary Engineering Center

Graphic Presentation of Biological Data for Water Pollution Survey Reports

William Marcus Ingram, In Charge
Biological Field Investigations
Water Pollution Control--and

Alfred F. Bartsch, Assistant Chief for
Special Technical Services
Robert A. Taft Sanitary Engineering Center

Graphical presentation of biological data may often be used effectively in demonstrating to both the layman and the technician varying impacts of pollution on aquatic life, while long lists of names of animals and plants become boresome, meaningless and will not perform the same function. Several schemes, each having merit, for reporting biological data collected on pollution surveys that have been published over the last few years, are those by Beck (1954) (1955), Kaplovsky and Harmic (1953), Patrick (1949), Surber (1953), and Wurtz (1955).

Bar graphs have proved to be especially effective in summarizing biological stream survey data. Usually they are readily understood and do not confound the issue, as frequently is the case with a myriad of long lists of scientific names that are appreciated only by the specialists who have prepared them. Lists of scientific names can be tabulated in the body of a report, with the translation of their significance into bar graphs that can be relied upon to present such data effectively to the general report reader. Many animal and plant species do not have universal common names; thus scientific names must be pronounced and used, if name lists are the basic mode of data expression incorporated in reports. In public talks also, such lists commonly add confusion and nullify the value of the basic data.

Figure 1 illustrates the use of horizontal bar graphs in summarizing lengthy tabular data that are often left to dangle in the appendix of a report. This figure demonstrates how three bar graphs may be combined to present a summary biological picture on a single page. If each graph were presented on a separate page, correlation, in telling the effects of pollution on the total kinds (genera) of animals and plants, would be less evident. The collections of aquatic life, on which this plate is based, were made in July and September of 1952 in "River A". The July collections were gathered after industrial production was curtailed as a result of a strike, and the great load of sustained pollution was from raw domestic sewage. September collections were made at the same stations after industrial production was resumed and resulting wastes to the river were superimposed upon those from municipalities. Variations in the total genera of animals and plants in July and September are shown on the right. Stations 11 and 14 represent control upstream stations.

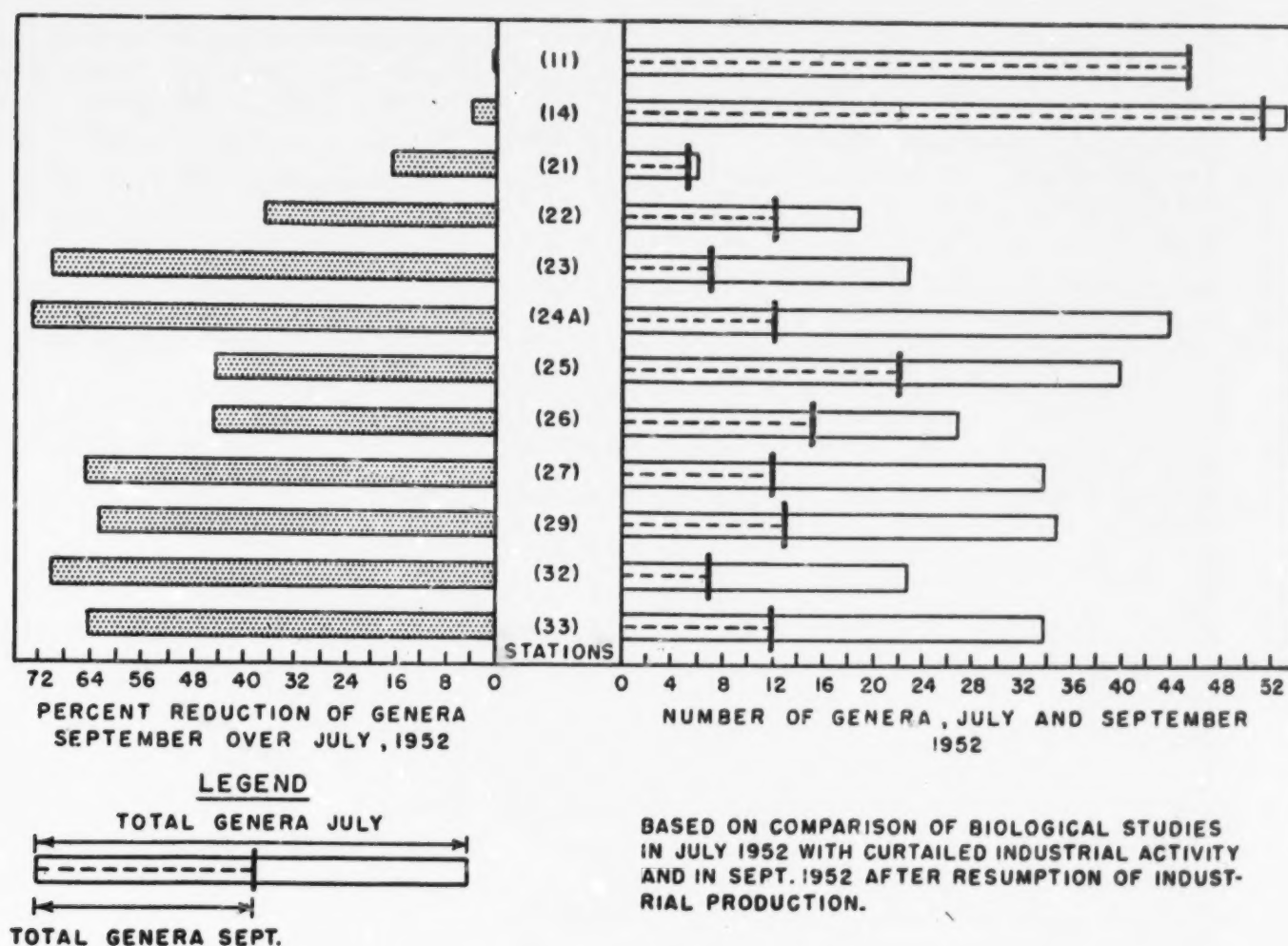


Figure 1. Effect of Industrial Wastes on Total Genera of Organisms, River-A

All other stations (21-23) are subjected to varying loads of municipal and industrial pollution. On the right are shown the suppressing effect of industrial pollution (September collections) on kinds of biota when such pollution was added to that of municipal sewage pollution (July collections). Variation in numbers of genera of plants and animals between July and September is not a result of any significant seasonal variation as is demonstrated in similarity of abundance at control Stations 11 and 14. The left portion of Figure 1 shows the per cent reduction of genera of animals and plants after resumption of industrial pollution.

Figure 2 portrays the use of a vertical bar graph in presenting a summary of the abundance of total genera of invertebrate animals and plants in a river as related to pollution. This figure summarizes, simply, seven typed pages of tabular data dealing with generic names of aquatic animals and plants found at each of nine stations distributed over 61.9 miles of "River B". Station 9 is a control station above major sources of municipal and industrial pollution.

Station 7 is another control station, on an unpolluted tributary stream that enters the main river at Mile 25.9, between Stations 8 and 6 where pollution has exerted its maximum effects in suppressing the variety of kinds of animals and plants. Other bars reflect the abundance of animals and plants at stations as related to varying effects of pollution on the river.

Figure 3 demonstrates the use of vertical bar graphs, superimposed over a pictorial map of an area, to show variation in bottom animals per square foot of sample in "River C". This graphical presentation allows one to locate sampling stations at a glance in relation to roads, railroads and towns. Illustrated are the effects that inert, inorganic solids from a glass sand operation may have in limiting the number of kinds and individuals of bottom animals. Productivity of Stations 2-4 on the south side of the River is contrasted with that at stations in unaffected stream areas such as Station 1 on the south side and Stations 1' - 4' on the north side. Stations 1 and 1' are control stations. Solids are carried into the main river from the tribu-

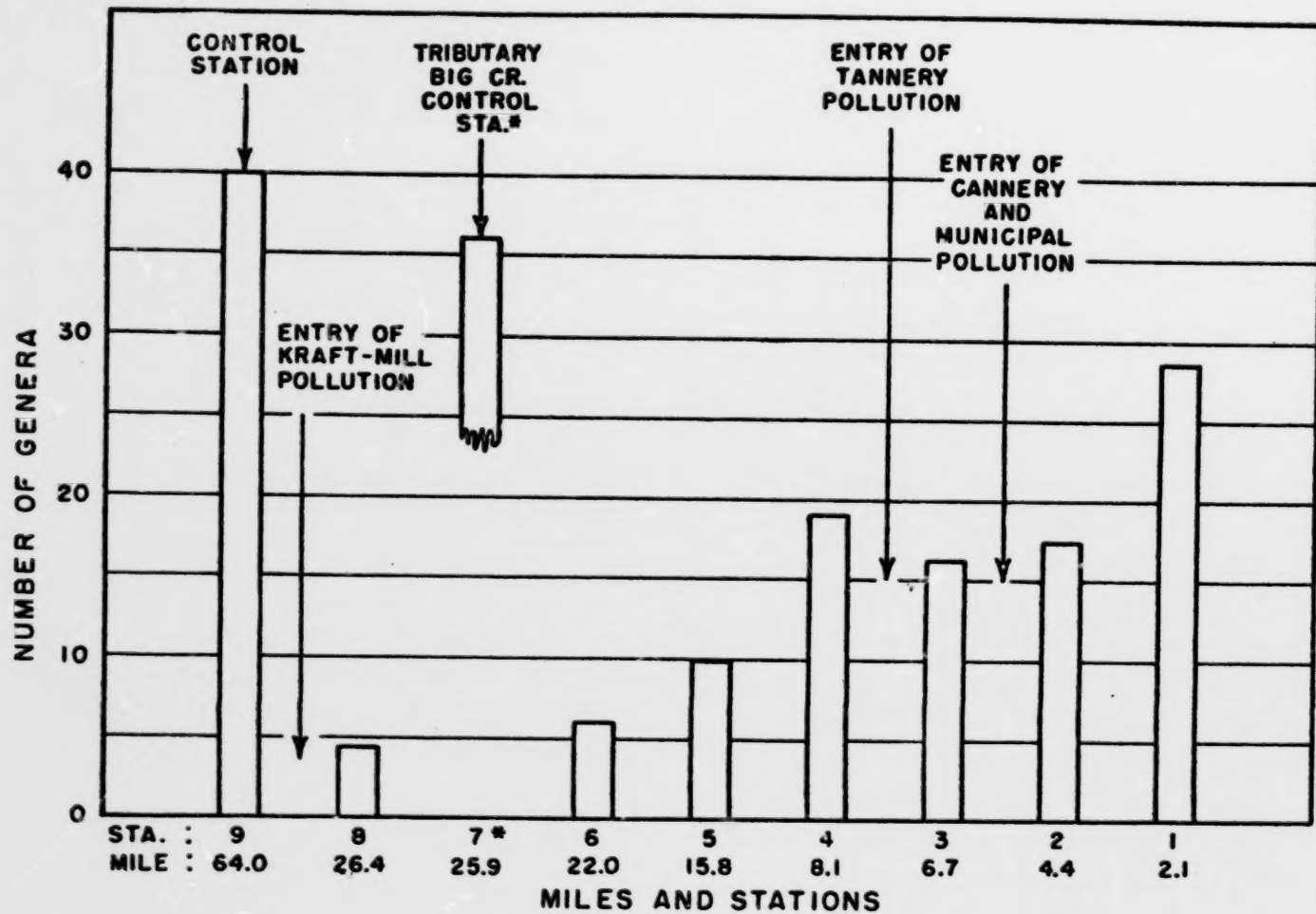


Figure 2. Total Genera of Organisms, River-B (September 1953)

*(This Sta., an Unpolluted Tributary) (Fish Excluded)

tary whose confluence is between Stations 1 and 2. Bottom animals are absent at downstream Station 2. Only one kind was collected at Station 3 on the south half of the bottom, while 7 were taken in the center of the river (3A), and 16 on the bottom of the north half of the stream (3').

ACKNOWLEDGMENT

The writers wish to express their appreciation to Harold N. Mullican, Chief Biologist, Stream Pollution Control, Department of Public Health, State of Tennessee, Nashville, Tennessee, for supplying data which were used in formulation of Figure 2.

REFERENCES

- Beck, W. M., Jr. 1954. Studies in Stream Pollution Biology. I. A Simplified Ecological Classification of Organisms. *Quarterly Journal Florida Academy of Science*, Vol. 17, No. 4, p. 211-227.
1955. Suggested Method for Reporting Biotic Data. *Sewage and Industrial Wastes*, Vol. 27, No. 10, p. 1193-1197.

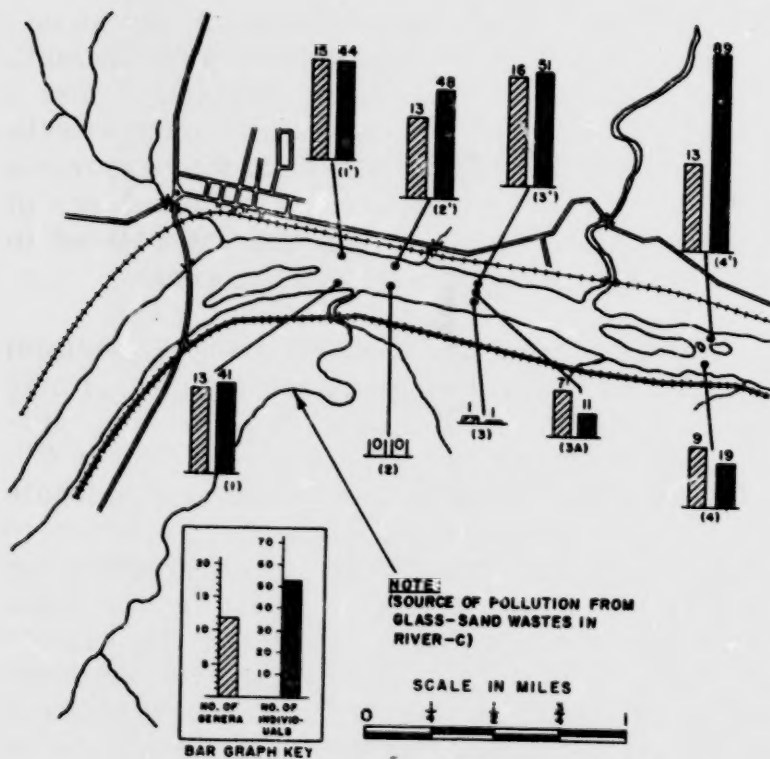


Figure 3. Total Genera and Individuals of Bottom Animals Per Square Foot, River-C, (September 1952).

Kaplovsky, A. J., and Harmic, J. L. 1953. Pollution Study of Red Clay Creek Drainage Basin. II. Determination of Existing Stream Conditions. *Sewage and Industrial Wastes*, Vol. 25, No. 9, p. 1072-1076.

Patrick, R. 1949. A Proposed Biological Measure of Stream Conditions, Based on a Survey of the Conestoga Basin, Lancaster County, Pennsylvania. *Proc. The Acad. Natural Sciences*, Vol. CI, p. 277-341.

Surber, E. W. 1953. Biological Effects of Pollution in Michigan Waters. *Sewage and Industrial Wastes*, Vol. 25:1, p. 79-86.

Wurtz, C. B. 1955. Stream Biota and Stream Pollution. *Sewage and Industrial Wastes*, Vol. 27, No. 11, p. 1270-1278.

Effective Methods for Collecting and Recording Data from Water Pollution Surveys

Eugene W. Surber
U. S. Fish and Wildlife Service,
Atlanta, Georgia

Streams or lakes with mud, silt, or even sandy bottoms yield a sufficient variety of organisms when sampled with a Petersen or Ekman dredge to illustrate water quality. The square foot bottom sampler is used to study shallow streams with gravel or rubble bottoms. Such streams are ideal for biological studies of water quality because of the great variety of organisms ordinarily present.

After the quantitative collection of samples, the following procedure was followed. (Samples were not picked in the field while the organisms were still alive since many of the oligochaeta, Tenebrionidae, and other organisms escape notice).

Each kind of organism was enumerated, identified to species, if possible, and designated as clean-water (C), facultative (able to live in moderately polluted as well as clean water) (F), or pollution tolerant (P). The percentages of organisms in each of these groups were used later in the preparation of pie diagrams.

An unpublished "Tentative List of Biological Indicators of Pollution" obtained several years ago from the Biology Section, Environmental Health Center (now Robert A. Taft Engineering Center), Cincinnati, Ohio, formed the basis of a list which was used for the classification of

the animals into the above categories. This list was added to from time to time, as the need arose.

After tabulation of the data, the total number of animals per square foot retained by a U. S. Soil Series 30 sieve (or equivalent nylon mesh size in the stream bottom sampler net) in each sample is determined.

Total number of species in each sample is important because it reveals whether a balanced or unbalanced population is present.

Table 1, is an incomplete tabulation made for a survey on the Pine River while the writer was Biologist for the Michigan Water Resources Commission.

A biologist might recognize from the arrangement of the data that the groups of organisms were arranged phylogenetically. More important, he recognizes the presence of certain groups, such as the mayflies and caddisflies, that are characteristic of clean-water habitats, or that unusually large numbers of tubificidae indicating polluted conditions are present at certain stations. The complete absence of organisms such as occurred in this example below a chemical plant at St. Louis, Michigan, is a rare occurrence, but this plant manufactured DDT and deposits of the crystals were present on the bottom in the samples taken nearby.

Gaufin and Tarzwell (1952) in the Lytle Creek studies showed that gross pollution was indicated by a reduction in species and by unbalanced populations of bottom animals. An unbalanced condition was indicated when a certain species became very abundant, often numbering over 500 organisms per square foot.

Polluted waters are characterized by

1. An unusually large total number of organisms in the sample (caused by unbalanced populations).
2. Very few or no animals present.
3. A reduced number of species.
4. A reduction in the percentages of clean-water and facultative animals, and a corresponding increase in the percentage of pollution-tolerant animals.

Table 1. Results of a Biological Survey of the Pine River above Alma to M-30, May 31, 1955
Number of bottom animals per square foot. (Incomplete Tabulation)

	Pollutional status	Above Alma, 125 yds. below bridge at Gulf Club			Below Alma Above iron bridge			Below Michigan Chemical Co.		
		Right	Middle	Left	Right	Middle	Left	Right	Middle	Left
Station Number		1	2	3	4	5	6	7	8	9
Depth in feet		3	6.5	4.5	3.5	9.0	8.0	9.0	8.0	11.0
Aquatic Earthworms:										
Limnodrilus	P	8	76	40	2,472	1,632	652	...	40	...
Tubifex	P	...	4	12	76	32	8	...	...	...
Dero	P	...	...	20	...	...	...	...	...	...
Stylaria	F	8	...	8	...	16	...	...	...	...
Leeches:										
Glossiphonia stagnalis . .	P	...	...	...	...	...	...	...	...	...
Mayflies:										
Hexagenia limbata	F	12	24	28	...	...	...	...	...	...
Dragonflies:										
Gomphus	C	...	...	4	...	...	...	...	...	...
Water Boatmen:										
Corixidae	C	4	...	4	...	...	...	...	...	...
Unknown Dipterous larvae? .	P (?)	...	...	...	...	...	...	...	...	...
Biting Flies:										
Heleidae (Palpomyia?) . .	F	8	...	8	...	...	...	...	...	...
Midgeflies:										
Tendipes decorus	P	56	...	4	...	4	...	...	...	...
Calopsectra dives	F	...	...	...	...	...	...	...	...	...
Tanytarsus tendens	C (?)	...	...	...	...	...	...	...	4	...
Polypedilum convictum . .	F	8	...	76	...	...	...	...	...	...
Cryptochironomus digitatus	C	...	...	12	...	...	...	...	...	...
Cricotopus bicinctus	F	...	...	...	...	...	...	...	...	...
Procladius sp.	P	32	...	4	...	...	...	...	...	...
Pelopia sp.	C	8	...	...	...	...	...	...	...	...
Unknown midgefly larvae .	C	...	...	4	...	...	...	...	...	...
Total animals per square foot		144	104	224	2,548	1,684	660	0	44	0
Number of species		9	3	13	2	4	2	0	2	0
Percentage clean-water . . .	(C)	8.3	0.0	10.7	0.0	0.0	0.0	0.0	0.3	0.0
Percentage Facultative . . .	(F)	25.0	23.1	53.6	0.0	1.0	0.0	0.0	0.0	0.0
Percentage pollution-tolerant	(P)	66.7	76.9	35.7	100.0	99.0	100.0	0.0	99.7	0.0

Pie diagrams were used to bring the definite biological conclusions to the technically untrained in this field. Figure 1 shows the results of a series of bottom samples collected in Green Bay, Wisconsin. The pie diagrams in lake surveys are placed roughly at the collection sites on the map. The larger the percentage of black in the diagram representing a sample, the greater the degree of pollution.

Where paper pulp mill or tannery wastes result in deposits of fiber or hair upon the bottom, the quantity deposited, based only on that

brought up in dredges, can be graphically illustrated by the following method. After removal of the bottom organisms, the fibers or hair collected in each 6 x 6 inch Edman dredge sample are deposited in a simple wooden frame 2 x 6 x 6 inches (I.D.) with bottoms of ordinary window screen. When the Petersen dredge is used, the inside dimensions are the same as the dredge opening (Figure 2). The fibers, hair, or other debris can be distributed evenly over the screen by flotation performed in a large photographic tray filled with water. The debris is then drained and the frame with debris placed

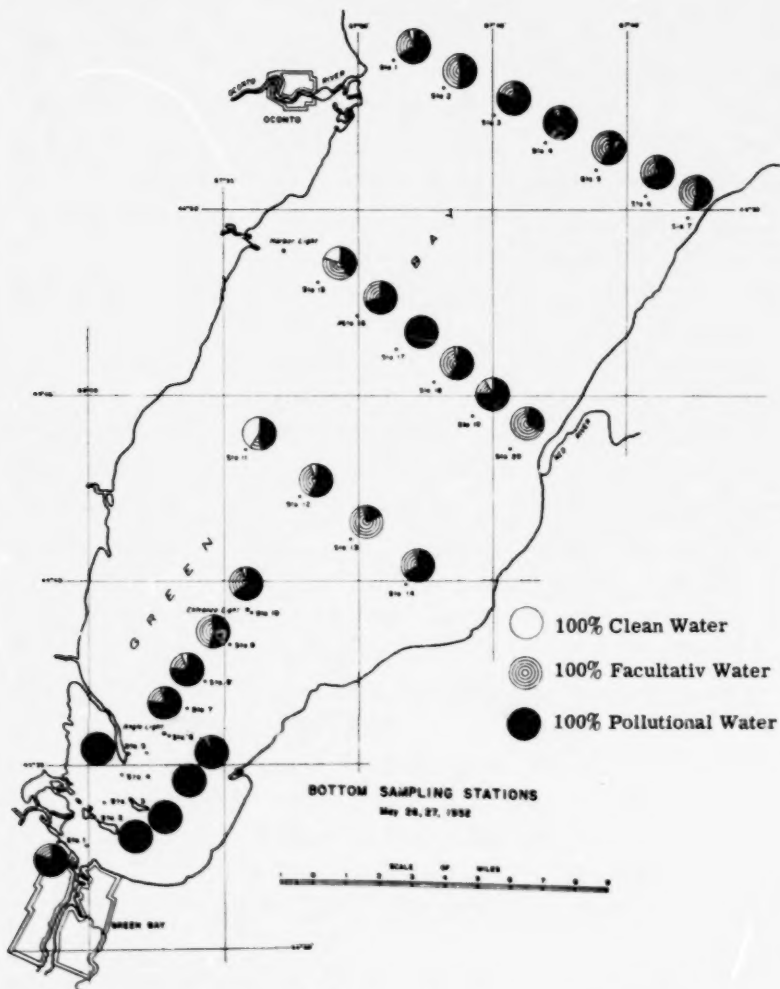


Figure 1. Green Bay, Wisconsin

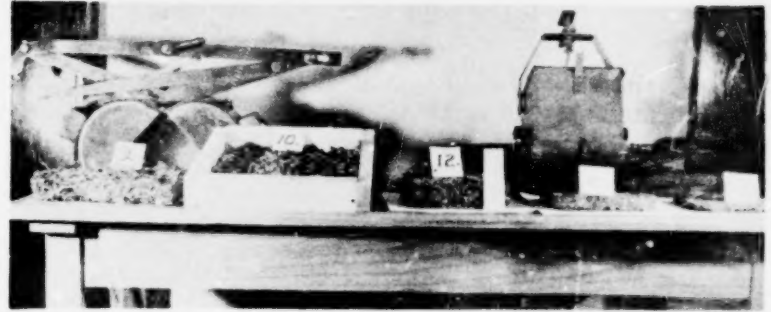


Figure 2. Wood chips and paper mill fibers form stable cakes after drying in an oven.

into an oven to dry at 60°C for a minimum of 24 hours, or until thoroughly dried. In the case of paper pulp fiber, the fiber forms an unusually strong cake. Fiber, hair, or debris, as the case may be, can be weighed and their percentage of purity estimated. These materials are readily weighed, and they hold together reasonably well for exhibits. Weights can be used for calculation of pounds per acre of bottom. The original collecting stations are spotted for mapping purposed by triangulation with two transits set a measured distance apart during the collection of the samples.

The results of a tannery waste survey of the east end of Lake Charlevoix (Michigan) is illustrated by the accompanying map (Figure 3) illustrating pounds of hair per acre on the bottom.

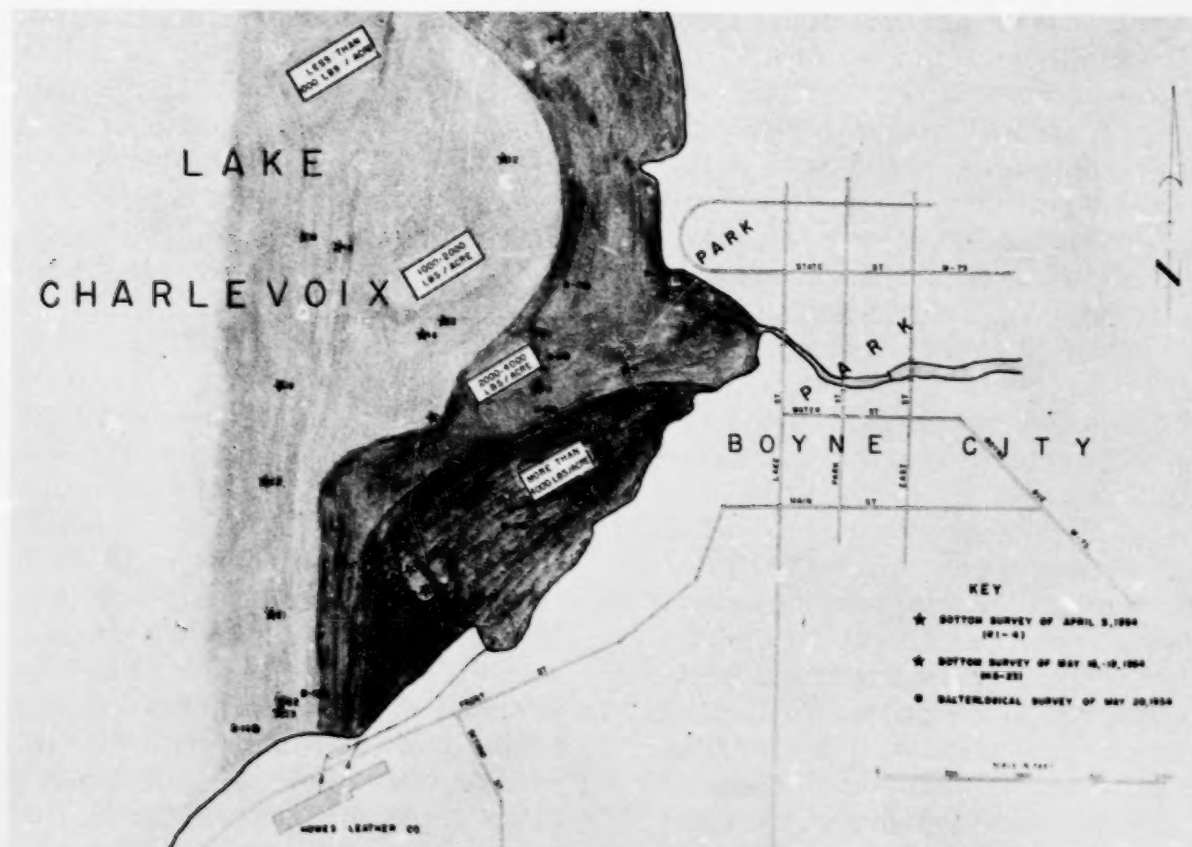


Figure 3.

REFERENCES

Gauvin, Arden R. and Clarence M. Tarzwell. 1952. Aquatic invertebrates as indicators of pollution. Public Health Reports, Vol. 67, No. 1, pp. 57-64.

Biological Stream Survey Data

Charles B. Wurtz
Consulting Biologists
610 Commerical Trust Bldg.
Philadelphia 2, Pa.

Efforts to correlate the relationship between prevailing stream conditions and pollution stems from concern over pronounced alterations in a stream. Almost always the biologist is asked to measure the extent of pollution. The biologist responds by measuring the deviation of the stream's biological structure from biological normality, and calling this deviation pollution. Properly this is only a measure of the degree of pollutional effect.

It is immediately necessary at this point to define "normality" and "pollution".

If a stream contains a total population commensurate with its geographic location, physical structure and water-quality characteristics it is in biological balance. If the water-quality characteristics are of natural occurrence, and if they fall within the natural range of such factors as these are commonly recognized in the historic development of limnology, then the stream may be considered biologically normal. As thus defined, all natural, unaltered waters are considered normal regardless of the composition of the contained fauna if that fauna is appropriate to the circumstances. This holds true for the oligotrophic headwater, bog lake, eutrophic river, concrete flume, or any other ecological habitat.

"Pollution" at times appears to be based on an inarticulate premise. All agree, however, that it is an alteration of a natural water by a human agency in such a manner that its usefulness has been impaired or destroyed for either consumptive or non-consumptive purposes by other parties. Destruction of the usefulness of water, and the concomitant damage to other interests, is the real interpretation of legislative definitions.

A biological stream survey that involves comprehensive faunal collections is done for one purpose only. This purpose is the measurement of prevailing biological conditions. Primarily the data collected are simply a description of the biological structure of the stream. If, when considering this description, it is realized that the stream deviates from biological normality considerations of pollution come into the study.

The particular data collected, and the method of presenting them for descriptive purposes, will be a product of the investigator's judgement and the peculiarities of the problem. For example, a study of fecal pollution will involve coliform samples and a fisheries problem will involve fish samples. However, the study of a stream as an entity with its overall biological characteristics is best accomplished by a study of the resident macro-invertebrate fauna. The study of these organisms requires the least time and the least equipment. Therefore they represent the most economical approach to biological stream surveys. The resident population of these organisms is also best adapted to interpreting deviations from biological normality. In general, most microscopic organisms tend to be transient in nature, sporadic in occurrence, irregular in distribution, and at the species level unavailable in replicate samples taken on a successive time basis. Fish are pelagic in nature, limited in numbers of species, with pronounced periodicity in reproduction, and evasive of irritants. Rooted aquatic vegetation is severely limited in distribution and has never been seriously considered as an adequate group for measuring stream conditions.

A list of the macro-invertebrate fauna present in a stream constitutes a biological description of the stream. If deviation from biological normality is observed the species of this fauna represent the data to be used for interpretation of the cause of the deviation.

The macro-invertebrate fauna includes a large enough number of species to permit the interpretation of stream conditions. At the same time, they are few enough in numbers that a small staff is capable of handling the necessary identifications. The diversity of physiological characteristics of these species make them especially useful for the biologist. Each species responds to influencing factors according to its physiological nature. For example,

as regards organic overloads, most macro-invertebrates can be conveniently placed as a tolerant or non-tolerant species. This does not hold for every species, of course, but it does hold for the majority of them. To gather data on most species as regards their response to organic loads is a burdensome task, but not an impossible task.

Organic pollution is more common than pollution by toxic substances. However, the response of the various macro-invertebrates to toxic material is diverse, and this diversity is an aid when reviewing the collected data as a prelude to seeking the cause of deviation from normality. Some data on species response to specific toxicants are available, but often the stream survey must be supplemented with toxicity tests if toxic materials are part of the problem.

The macro-invertebrate fauna can be conveniently separated into five basic ecological types. These are the burrowing forms, sessile forms, foraging forms, pelagic forms and planktonic forms. Other arrangements suggest themselves, but these have proven to be the most useful. (Plankton would not be included in a stream survey since plankters present in streams are predominantly tychoplankton). The proportionate part of each ecological type in a total population is a product of the physical structure of the habitat. In a mature, rubble-bottomed stream the burrowers usually represent 10-15 per cent of the population, the sessile forms 10-15 per cent, the foraging forms about 60 per cent, and the pelagic forms about 10 per cent. The reduction or elimination of any of these ecological types can be used in the interpretation of stream conditions. Excessive siltation, for example, will destroy the sessile forms as well as some of the burrowers. Transient slugs of toxic materials are resisted by the burrowers. Other phenomena can also be readily recognized by the response of these ecological types.

The use of the macro-invertebrates as the biological stream survey data is further enhanced by enabling the biologist to interpret the stage of stream alteration and whether or not the stream is being further depressed toward a poorer biological quality, recovering from a poorer biological quality, or in equilibrium with prevailing conditions. The macro-invertebrates as data are used in conjunction with the standard water-quality criteria for these interpretations.

When the normal fauna of a particular ecological habitat is known it is possible to measure the degree of deviation from biological normality and to express it as a percentage. This is a very useful adjunct to the macro-invertebrate survey because it enables us to make direct numerical comparisons between the various parts of a stream that deviate from biological normality in varying degrees.

HOW CAN THE BIOLOGIST BEST FUNCTION IN WATER POLLUTION SURVEYS?

Discussion Leader

CARLOS M. FETTEROLF
Water Resources Commission
Lansing, Michigan

Of the approximately 60 persons in attendance, about 20 participated actively. The group concurred that the function of biologists in pollution surveys is to demonstrate effects of pollutants on biota of receiving waters and to integrate this phase into water pollution surveys as a whole. Discussion centered on a basic theme of establishing mutual understanding between sanitary engineers and biologists.

An early conclusion was that communication between the groups, which has been regrettably low, is on the upswing. To implement this trend some of the leading engineering schools include courses in biology for their sanitary engineering students. Similarly, professors of aquatic biology are placing more emphasis on chemistry, physics, and statistics. These approaches will inevitably draw the profession onto more common ground than they already share. Several speakers commented on the overlap of the fields and the trend towards understanding between the groups. Both engineers and biologists spoke of minimal differences and excellent cooperation existing within their agencies.

Aspirations towards standardizing methods in pollution surveys were expressed and the suggestion of a committee was made. While it was conceded that universal methods, once established, would be more easily communicated to others than biologists, the diversity of

situations makes standardization extremely difficult. Little enthusiasm was shown by the group towards formation of a committee.

Before commenting on this subject I must establish my position so you may understand the angle from which these thoughts are presented. I am the only aquatic biologist working with 15 sanitary, civil, and hydraulic engineers for the Michigan Water Resources Commission. This Commission has been charged with pollution control since 1929. Twenty-four years of successful operation preceded the hiring of the first aquatic biologist, E.W. Surber, whom I succeeded in 1957. We have been well received and have made valuable contributions to the Commission program.

While preparing these comments I am under the belief that most people in the Cincinnati audience and future readers will be either aquatic biologists or sanitary engineers. The control of pollution is essentially in the domain of both groups. However, the biologist usually finds himself writing reports for submission to the engineer in charge of the pollution control agency or the wastes engineer of the industry requesting the biologist's survey. Sanitary engineers dominate the field of pollution control and therefore the question of how the biologist can best function in water pollution surveys involves cooperation between biologist and engineer. Without mutual understanding there will be disagreement on the three most important aspects of pollution surveys; objective, approach, and interpretation.

These factors can only be established through communication, a notably underdeveloped skill among engineers and biologists. Unfortunately most communication between the groups is osmotic, a slow process when thick membranes are involved.

Since biologists are the minority group we must play the diplomat's role in most instances. We must first accept waste disposal as a part of the modern life we enjoy. Pristine aquatic environments do not go hand in hand with industry and expanding populations. The economic climate cannot be held back because of desire for unsullied water quality. Conservation is involved with "wise use" and "multiple use" objectives. The biologist should recognize these policies and not be ready to use the term "pollution" whenever he notes a response to enrich-

ment by slight variety alteration or a minor population depression due to an inhibiting agent. The biologist's duty is to evaluate these shifts and remember the objectives of the particular survey he is involved with. The engineer in the administrative position and the commission deciding on the action necessary may well remember the fable of the boy who cried, "Wolf!"

Economics are still involved when we consider the limited money and personnel available to the majority of state agencies charged with pollution control. The established objective in most pollution problems is a moderation of waste loading. It is up to the biologist to integrate his program with that of the engineer and then proceed with the most direct approach that he feels will illustrate biological damage. Engineers and commissioners are not concerned over extraneous data which the biologist feels is of great ecological and technological importance. Expenses go hand in hand with time and the administrator will look critically at excessive detail.

There are three points in the foregoing comments which cause the biologist to modify his actions.

1. In extreme cases of pollution where biological evidence could simply and efficiently pinpoint the damage there is usually no need for a biological survey. If the biological data are superfluous to the chemical and physical data gathered by the engineer, the biologist probably shouldn't be on the survey at all. Therefore, when a biological survey is called for, the problem will most likely be a borderline case requiring involved explanations and thorough analysis of the biological situation to illustrate significant degradation.

2. Few investigators outside of agencies involved with pollution control are gathering the ecological information sorely needed as tools for pollution biologists. These data must be accumulated somewhere. It is up to the individual biologist to decide what portion of his time he may allot for collecting these data which are not essential to his immediate purpose.

3. Opinions formulated by biologists during reconnaissance surveys are easily, quickly, and correctly made by reference to those groups of organisms which best reflect the conditions under which they live. Deviations from the

theoretical norm are usually simple to detect by the experienced man. However, specific identifications and numerical tabulations on an area basis become important in three instances: in a courtroom; in following trends; and in making future comparisons.

The above situations often force the biologist to more detail than the engineer and the biologist himself deem necessary for the short term objective. Mutual consideration of these factors will lead to greater understanding.

Engineering methods in pollution study are relatively fixed. Standard methods for measurement of waste loading, physical factors, and chemical properties are widely recognized. By using these standard procedures engineers are usually able to prepare reports shortly after completing their field survey. Exceptions occur if many observations are desired in determining rate (rate of reaction), or if the self-purification capacities of the stream are to be determined. The usual engineering data lend themselves well to mathematical analysis, numerical tabulation, and graphical methods of presentation.

The biologist, well aware of complaints concerning his lengthy discussions of biological principals, variety alterations, etc., has adapted the graphical presentation methods of engineers in an attempt to be concise. It is difficult to fit the diversified situations to be interpreted into a standard presentation for rapid evaluation by specialists in other fields. I am unaware of a graphical method which can fully illustrate the biotic dynamics of a problem area. The biologist's written explanations and interpretations must accompany any graphical presentation.

Biologists must communicate the difficulty of presenting dynamic data as facts and figures to the engineer, but they must also sum up their analysis in definitive terms which leave little doubt as to their conclusions.

As meat for further discussion let us consider the overlap within the fields of a sanitary engineer and a pollution biologist involved with water pollution surveys. Both men are perfectly capable of collecting water samples for any determinations to be made at a later date by a chemist or bacteriologist. Field chemistry, echo sounding, conductivity, turbidity, and transparency readings can be done by both men. Estimation of depth of sludge deposits by the

use of bottom sampling equipment is not entirely the biologist's prerogative, nor is mapping or measurement of stream flow the engineer's. While bioassay is a biological measurement the engineer is free to use this tool. Whose domain do radioactive wastes and the elusive rare chemicals and insecticides fall into? Which man will claim taste tests as his exclusive tool? Under the heading "engineers only" we have waste surveys, self-purification capacities, and contacts with industry and municipalities regarding waste control procedures. Under "biologists only" we find the collection and identification of aquatic plants and animals, coupled with interpretation of the communities found.

The tremendous mutually shared area points out that the biologist can best function in pollution surveys as an integral part of the whole, not as an addendum; provided he can devise methods of analysis which will place him on a reasonably similar time basis with the engineer for reporting results.

THE EFFECTS OF EROSION, SILT, AND OTHER INERT MATERIALS ON AQUATIC LIFE

Discussion Leader

JOHN WILSON

U. S. Public Health Service
Regional Office, Portland, Oregon

The conservation of our water resources is assuming increasing importance throughout this country and the world in general. By conservation is meant wise use with an eye to the future. Cooperative interagency groups have been active for a number of years on our major river valleys in the matter of equitable allocation of these valuable resources for power, flood control, navigation, agriculture, industrial and municipal water supplies, fisheries, and recreation.

Early in the development of these programs, the allocation of waters quantity-wise has been of prime consideration, but in more recent years the importance of guarding water quality is gradually being recognized, for it has been said that polluted water is as bad as no water at all.

Sand, silt and clay from eroding watersheds, gravel washing and road building operations, placer mining, deforestation, overgrazing, unwise irrigation, and other agricultural practices cause degradation of water quality and damage to downstream water uses as does pollution from municipalities and industries. Yet we are continually reminded that silt and other inert materials are native to the watershed, that erosion has been going on for eons of time before the advent of man; therefore, why be concerned? There are two answers to this query: (1) These natural materials are damaging to many legitimate water uses, and (2) through the engineering genius of man, they are subject to some degree of control.

Exploration of a part of the first answer was the core of this discussion; namely, adverse effects of silt and turbidity on aquatic life.

INTERFERENCE BY SUSPENDED MATTER - TURBIDITY - ON THE PENETRATION BY LIGHT INTO WATERS

Emphasis throughout the discussion has been laid upon importance of developing better field and laboratory methods for all such measurements as turbidity and the like. Reference was made to the detailed discussion by Dr. Harry K. Phinney in the siltation symposium held in Portland, Oregon, March 23-24, 1959, in which was stressed the importance of better measurements of penetration light into waters. The measurement of rate of productivity based on photosynthesis of algae provides a better understanding of adverse effects of turbidity and suspended matter than can be deduced from measurements of turbidity.

Dr. William Irwin, Oklahoma State University, Stillwater, reported on his research in Oklahoma. He stated that a number of reservoirs when first constructed started out with quite clear water, but as time went on they tended to show an increase in turbidity and siltation which eventually prevented reproduction of bass, shad, and flat-head catfish. The study showed that increased turbidity and siltation on the bottom of the reservoirs decreased photosynthetic activity of algae and smothered bottom organisms so that only a few could be found. The adult fish lived and thrived quite well feeding on smaller fish but the freshly-hatched spawn of these species apparently had

no food on which to feed until they could grow large enough to feed on other fish.

SMOTHERING OF BOTTOM-DWELLING ANIMALS AND PLANTS BY SILT

Deposits of silt fill cracks and crevices between rocks and smoothe out gravel beds, thereby reducing the surface area available for growth of attached algae and higher plants and for the associations of animals that grow with these plants. Perhaps more importantly, such deposits radically change the benthic environment, i. e. the substrate and the physical characteristics relating thereto. A combination of instability of attachment with the devastating molar (abrasive) action that often takes place usually results in sharp reduction in organisms, both plant and animal.

Organisms that normally live attached to stones in fast current or make their habitat in sheltered spaces under rocks in riffles when faced with encroaching siltation must either adapt themselves to life on soft, shifting bottom, migrate or die.

A number of illustrations were cited to show where field investigations indicated marked reduction in productivity of fish-food organisms in streams receiving heavy loads of silt, compared to other sections of these same streams not receiving such discharges of silt. Examples are Powder River in Eastern Oregon (1) and Wynoochee River in Washington (2).

IMPAIRMENT OF FISH SPAWNING SUCCESS

Reference was again made to the siltation symposium and to the field equipment which was demonstrated on the first day of the symposium. The use of standpipes and permeameters were discussed. Reference was made to the work of Wickett (3) and Cooper (4) of the Fishery Research Board of Canada and International Pacific Salmon Fisheries Commission, respectively.

The importance of maintaining free flow of water through spawning gravels was stressed as a means of maintaining high dissolved oxygen content of water passing over the eggs in the gravel. Deposition of silt from an upstream source of land-wash or gravel-washing opera-

tion, from mining operations, earth slides, from road building, deforestation, or some similar source can, and often does, destroy the eggs in spawning gravel by reducing the flow of water, thereby the necessary oxygen. Fine silt actually coats the surface of the egg, thereby interfering with gaseous interchange at this membrane.

ADVERSE EFFECTS OF TURBIDITY AND SILT UPON THE CAPACITY OF NATURAL WATERS TO ASSIMILATE WASTES

Reference is made to the natural purification potential inherent in all waters. An illustration was given of the heavily silted Bear River in southeastern Idaho and northern Utah (5). Here the stream is so heavily silted and carries such heavy concentrations of inert suspended matter that the sugar mill wastes and partially treated sewage from municipalities in the area are not assimilated in a satisfactory manner. This is an interstate pollution problem where an organic waste problem is superimposed upon a siltation problem.

Turbidity and silt tend to adsorb pollutants and, to a certain extent, stimulate flocculation of organic matters, thereby enhancing sedimentation. Indeed it has been suggested by Dr. Hoffman of the U. S. Department of Agriculture, the panelist on the daytime discussion on pesticides (this Seminar), that siltation might be induced downstream from an area that has been sprayed with certain insecticides as it has been found that adsorption of the toxic material from the insecticide by silt brings about a much more rapid detoxification in the waters than would otherwise take place in a clear stream.

EFFECTS OF TURBIDITY AND SILT UPON SHELLFISH IN ESTUARIES

Dr. Victor Loosanoff gave a brief illustrated talk on some research work then in progress at the Laboratory of Fish & Wildlife Service in Millford, Connecticut, on the effects of silt upon oyster development. He showed an apparatus that was devised for maintaining uniform concentrations of silt in plastic laboratory bottles sealed with an air space. The test animals were oyster larvae. These bottles are placed in a large wheel-like machine which keeps turning slowly, thereby inverting them periodically. Four kinds of material are used to induce

siltation: ordinary silt which is a clay-sand mixture, chalk, kaolin, which is clay, and Fullers earth. The least damaging was found to be silt; up to 3/4 of a gram of silt per liter did not show any change. Above this concentration, development of the larvae was arrested at the straight hinge stage. Up to when concentrations of silt were increased to 4 grams per liter, the larvae lived but didn't grow. Fullers earth was found to be the most damaging of all the substances tried.

Experiments have also been conducted to determine the pumping rate of oysters and clams in the presence of induced concentrations of kaolin, silt, and chalk. In this instance chalk was the most damaging with the reduction of pumping rates approaching 90 per cent at 1-1/2 to 2 grams per liter.

STANDARDS OR CRITERIA

In regard to prescription of standards or criteria for permissible levels of turbidity and settleable inert material in waters, it was agreed that the present state of knowledge does not allow establishment of firm criteria. However, it was agreed that much realistic control and progress has been made where problems are handled individually and control measures are "tailor-made" to meet the needs in specific cases.

REFERENCES

1. Wilson, J. N. 1953. Report on Biological Reconnaissance on the Effect of Gold Dredging and Mining Operations on Powder and Burnt Rivers, Oregon. An unpublished report prepared cooperatively by the Oregon State Game Commission, Oregon State Sanitary Authority and Division of Water Pollution Control, Public Health Service.
2. Ziebell, C. D. 1957. Turbidity and Siltation Studies - Wyoochee River, Washington. Washington Pollution Control Commission, Olympia, Wash. Unpublished Report.
3. Wickett, W. P. 1954. Jour. Fishery Research Board of Canada, 11(6):933-953.
4. Cooper, A. C. 1956. A Study of the Horsefly River and the Effect of Placer Mining Operations on Sockeye Spawning Grounds. International Pacific Salmon Fisheries Commission, New Westminster, B. C.
5. 1955. U. S. Department of Health, Education and Welfare Water Supply and Water Pollution Control Program - Report on the Investigation of Pollution in The Bear River System - Idaho - Utah, (Unpublished).

HERBICIDES

Discussion Leader

CHARLES R. WALKER
Missouri Conservation Commission
Jefferson City, Missouri

The control of aquatic weeds is a major problem in the management of fishery waters and recreational values are often impaired by the physical interference of weeds with fishing and boating. The public health aspects of aquatic vegetation control are important to the control of weeds causing water taste and odor, interference in waste treatment and the harboring of obnoxious insects and the "swimmers itch" organism. Dense stands of vegetation have repeatedly caused crowding and stunting of fish populations. Even more serious are the occasional partial or complete kills of fish populations caused by oxygen depletion as plants decay. Some types of algae are even poisonous to fish and other animals which use the water. The search for more effective ways of controlling these troublesome aquatic plants is urgent. The rapidly expanding agricultural chemical industry has brought many new herbicides to the market which might be applicable to this need. However, most of these products are designed for weed control in agriculture and are untried in water environment. Consequently, extensive testing to determine their effectiveness on aquatic plants and a critical evaluation of both the acute and chronic toxicity to fish and fish food organisms are imperative to determine their place in the herbicidal program.

Herbicides must be screened for measurement of toxicological properties to fish and fish food organisms as well as the phytotoxicity in the aquatic environment. Bioassay methods should include determination of the acute toxicity to fishes and other organisms over periods of time of not less than 96 hours and preferably for longer periods. Testing in continuous flow systems or under field conditions with maximum control over natural indeterminate factors is most important. One approach to this problem of field testing is the technique used in Missouri experimental work which will be described in the Vol. 7 No. 3 issue of the Weed Society of America journal. This involves the use of the plastic weed control enclosure which allows plot

replication in addition to the critical observation of herbicidal effects on the fauna and flora. The influence of water quality, colloids, organic or biological systems on the herbicidal chemical and its toxicology should be studied further. Herbicides should be tested in plots of sufficient size for proper evaluation of their properties. Water density currents, colloidal or organic uptake, biological interference, formulating agents as carriers, solvents and wetting agents may have profound influence on the distribution and effects of the herbicide in the aquatic environment. More attention needs to be given to properties of formulating agents and the quality control of their formulation. Suggestions were made for the standardization of formulation with code numbers being given to batches and better information on the composition of the materials with special reference to percentage composition, activity and definition of inert ingredients by the chemical industries.

A great deal of information was exchanged on the levels of phytotoxicity of various herbicides (silvex, simazine, 2,4-D, endothal, sodium arsenite, dichlone, dalapon, monuron, diuron and others). There was an interesting note on the variety of results with different geographic locations both in phytotoxicity and toxicity to fishes. The tainting of fish flesh and other sublethal effects of herbicides were also discussed. It was pointed out that many of the solvents, wetting agents and carriers were a likely source of trouble in producing these undesirable effects. Chemical oxygen demand as well as the biological oxygen demand were important factors in the practical aspects of weed control as well as in pollution abatement. Chronic toxicity and degradation of the fishery is likely to be overlooked in many short-term investigations even though it may be more significant than the acute toxicity aspects.

The formulating of herbicides on attaclay or volclay to make granules or pellets offers real promise in aquatic weed control programs. Selective weed control may also be achieved in limited areas such as beaches, boat docks, lanes and landings. The material is easy to apply and distribution is calculated on area rather than volume basis. This should give more effective control, higher residual effect, minimized toxicity to fish and better efficiency and economy of materials used.

OIL REFINERY WASTE PROBLEMS

Discussion Leader

ROBERT A. LAFLEURDivision of Water Pollution Control
Louisiana Wild-Life and Fisheries
Commission

It was generally agreed that waste control council type organizations among oil refineries has proven to be a very valuable development in approaching and solving pollution problems confronting refineries.

The benefits derived from such organization are basically of two types. They are: (1) the actual exchange of ideas of a technical nature has been quite valuable and (2) the public relation benefit and desirable publicity derived through this medium has been well worth the time and funds expended. It is the opinion of the panel chairman, supported by the opinions of other members of the panel discussion that stream pollution arising from oil refinery wastes discharges is very definitely the responsibility of the refineries. Reasonableness and temperance, however, are two factors that should play a very important part in negotiations on the part of any water pollution control agency with oil refineries.

Another idea that appeared to prevail with respect to stream pollution resulting from refinery waste was that cooperation with refinery managements and education of unit operators within the refinery can and will provide better and/or more satisfactory solutions to refinery waste problems than, for example, the attempt of enforcement of existing laws on statutes books. There is no suggestion implied here that law enforcement does not have its place in controlling and/or abating stream pollution from these or any other sources.

Refinery Waste Problems

Robert A. Lafleur

Division of Water Pollution Control
Louisiana Wild Life & Fisheries Commission

The problems encountered in handling refinery wastes have become increasingly important in recent years. This situation has been brought

about by a number of factors; among these are industrial expansion and substantial population increases, both of which have produced an ever-increasing demand for greater amounts of water of acceptable or better quality. Thus, in this instance, as in dealing with any problems involving discharge of waste material to streams, two cardinal considerations and requirements make themselves emphatically self-evident; these are the availability of adequate quantities of water of acceptable quality, and the protection of receiving streams by adequate waste treatment facilities that are not economically prohibitive.

In approaching the problems of handling refinery wastes it soon becomes apparent that some discharges from oil refineries can be returned to a receiving stream without treatment because they contain no materials that can be harmful to the stream. The effluents could and should be segregated on the basis of their potential ability to cause harmful effects to the receiving water body.

In considering those refinery wastes that are capable of harming the stream, manner of treatment of these wastes are as varied and/or numerous as the different types of effluents. The ensuing discussion is intended to mention some of the varied and numerous waste treatments that are today being employed by refineries in the State of Louisiana.

Since the turbidity of the water of the Mississippi River has a range of 200 to 800 p.p.m., in using this very turbid water oil refineries located on its course encounter difficulty in its use. This silty water receives no treatment; consequently, silt does come in contact with petroleum products; hence, disposal of this petroleum bearing silt to the river is most undesirable. In many cases, oily silt has been used to build up low sections of real estate. More recently silt removal is being attempted with the use of high speed centrifuges. Results of this type of treatment will be evaluated at a later date.

In the case of one refinery, the temperature of the effluent discharge to the river was recorded as high as 45°C. It was felt that this probably created a passage barrier to fish and/or other aquatic life, and since the discharge site and water intake were in close proximity, recirculation became a problem. Because of

the higher temperature, larger quantities of water were required for adequate tower cooling. To correct this situation, the refinery constructed a wide, shallow canal that paralleled the river for approximately one-half mile. The temperature decrease effected was significant in that lesser quantities of water were required for adequate cooling in refinery process.

Another problem facing oil refineries is that of the disposal of sulfide bearing waters that collect in the reflux drums of refinery equipment. The disposal system most commonly used for these, so called, sour waters is steam stripping. Basically, the sour water stripping system is composed of three parts: (1) a gathering system, (2) accumulator sump with pump, and (3) the stripping tower. The sour water (sulfide bearing water) is collected from topping units, catalytic cracking units, and catalytic fractionation units. In operation, waters collected in the gathering system are accumulated in the sump, skimmed of oil, and pumped to the stripper tower. At this point in the process, the stripped gases are introduced to and burned in the acid plant furnace.

The problem of oil recovery from waste effluent has been and still remains a vexing one. Arbitrarily, the water pollution control agency in Louisiana has set a maximum of 30 p.p.m. oil content in refinery waste discharges. It is realized, in setting such a maximum on oil content in effluent waters, that not all refineries can or do discharge no more oil than this at all times; yet here a goal has been set that refineries can and do work toward. Numerous methods have been and are being studied for reducing oil content in effluent discharges. For example, the idea of air flotation and subsequent oil skimming has been considered; to a degree this has proven satisfactory; however, air flotation has its limitation in large scale operations. The API type separators are most generally in use at the refineries. With respect to handling of effluent waters, prior to discharge, the following described treatment is typical. The primary separator receives all of the refineries' more contaminated waters; these include waters containing heavy oils, solids, and oil emulsions. Settling time in the primary separator is approximately one-half hour. The effluent leaves the primary separator and is then discharged to the large master separator where it is mixed with all other previously segregated and lesser contaminated water.

This master separator is referred to as the final step or clean-up in effluent treatment prior to discharge to the stream.

Phenol removal from refinery waste water has claimed much attention of those charged with refinery waste treatment. This removal and/or destruction is a necessity due to taste and odor problems caused in domestic water supplies, the undesirable taste in fish and other aquatic life where phenol concentration is below toxic levels and in instances where phenol concentrations are at or above toxic levels with resultant fish mortalities. The problem has manifested itself chiefly in streams from which municipal water supplies are being taken. The Mississippi River is a prime example of such a stream. Some eighteen municipalities located on the river's course and downstream from the huge industrial complex in the vicinity of Baton Rouge, Louisiana, obtain their water from the river. This water supply is meeting the demands of over one million people. Extensive treatment is, of course, necessary in making this water potable. The presence of oil and/or phenols in the river water significantly increase chlorine requirements during treatment. It is worthy of comment at this point that phenol containing waters have an even more disagreeable taste after chlorination. The removal of phenols is being accomplished by two methods. First, sour water has been segregated from other effluents and subsequently pumped into injection wells. The only possible hazard in injecting phenol bearing water is the contamination of ground water strata from which domestic supplies are taken. This danger is not considered very serious. The second method is popularly known as the biological oxidation of phenols. Commonly, this type of phenol destruction is accomplished in sanitary sewage treating systems. The Shell Oil Company refinery at Norco, Louisiana, has conducted rather extensive investigation into the intricacies of phenol oxidation. Their studies indicate that about two-thirds of their total phenol reduction occurs between mixing with the domestic sewage and the sewage plant entry. Of the remaining phenols, approximately 5 percent to 10 percent is destroyed in an Imhoff tank, 80 percent to 90 percent in the trickling filter and as much as 5 percent in the secondary settling tank. In summary, then, it can be said that the sanitary sewage plant itself effects a phenol reduction of 85 percent to 90 percent. There are a number of factors that influence the biological oxidation

of phenol; these are, temperature -- since bacteria have an optimum temperature, metabolic lag which involves the acclimating to a varying environment, phenol concentration changing and accompanying sudden pH changes, since conditions such as these can easily destroy or seriously reduce the bacterial culture in the sewage treatment plant.

Other problems which are by no means any less troublesome but are directly or indirectly related to those mentioned earlier in this discussion, are the handling of tars and asphalt, and finely divided particles of oily silt that will rapidly settle to stream bottoms, the ability of a stream to assimilate organic and inorganic chemicals and hence prevent overloading, and the ever present danger of oxygen depletion due to a heavy BOD load either via a high p.p.m. and/or a pounds per day value. The solutions to these problems are being sought by the use and/or improvement of oil recovery and separator procedures, the use of oxidation ponds for BOD (IOD) stabilization and temperature reduction of effluents at or prior to effluent discharge to streams. At the Esso Standard Oil Refinery in Baton Rouge, Louisiana, waste control personnel are making use of gold fish in each of two aquaria as an indication of the quality of their effluent. Through one aquarium water is pumped in from the river, while passing through the other aquarium is the plant effluent discharge. A seemingly minor difficulty that has plagued refineries in Louisiana is that of devising a satisfactory sampling procedure for determining oil content in effluent discharge. It is felt that the grab sample procedure, for example, has proven unsatisfactory because of excessively large variations in values obtained. Composite samples, then, taken at a properly selected location are apparently the answer to this problem. The cardinal requirement in this properly selected location is that it must provide a good representative sample.

We in Louisiana have a unique organization, the Louisiana Petroleum Refiners Waste Control Council. The membership of this council is made up of representatives of six of the largest refineries in the state. Some of these oil refineries are among the largest to be found anywhere in the world. Also included in the aforementioned membership is Louisiana State University and the water pollution control agency of the state. The organization meets quarterly for a free and open discussion of problems

facing individual refineries and also those problems common to all member refineries. The exchange of ideas relative to solution of refinery waste problems has proved of untold value to all concerned in the decade or more years since the inception of this organization. In addition, and as its contribution to further the knowledge regarding effluent characteristics, Louisiana State University through its Department of Zoology and certain members of the faculty conduct certain basic researches that aid immensely as a guide to effluent handling and/or treatment. Graduate level students (Master and PhD candidates) conduct these researches while on fellowships that are financed by assessments of the member refineries and administered and supervised by the University. Specifically, the research work is composed of two basic types of bioassay tests using fish and selected invertebrate species. In the first type, bioassay tests are conducted on actual refinery effluents while in the other, specific pure chemicals known to be present in refinery effluents are utilized. The basic research conducted on specific pure chemicals found in refinery effluents has produced very valuable information. Typical of this information are the following: (1) the establishment of a reproducible method for determination of toxicity tolerances of fish and Daphnia magna, (2) the development of a suitable method for the use of Daphnia magna as a toxicity test animal under the existing laboratory conditions, (3) the development of a method that may be used for testing the toxicity tolerance of Daphnia magna to solutions containing volatile components, and (4) the demonstration of the effect of lowered oxygen tension on toxicity thresholds for Daphnia magna and other aquatic animals. In this manner, toxicity thresholds to these materials are established which aid the refineries in devising methods for effluent treatment, control and discharge. The data obtained by the graduate students holding these fellowships are applied in fulfilling dissertational requirements for graduate degrees.

As refinery waste problems arise, the solutions to these problems are sought by waste control personnel at the various refineries, aided and abetted by others such as the previously mentioned research group, the Louisiana Stream Control Commission and its fact-finding group, the Division of Water Pollution Control of the Louisiana Wild Life and Fisheries Commission.

ACKNOWLEDGMENTS

The writer wishes to gratefully acknowledge the assistance, information, and suggestions furnished him by Dr. J. E. Miller of Esso Standard Oil Company of Baton Rouge, Louisiana, and Mr. Ben S. Graves of Shell Oil Company, Norco, Louisiana, without whose assistance this paper would have been difficult to write. Appreciation is expressed also to Mr. K. E. Biglane, Chief, Division of Water Pollution Control, State of Louisiana, and Dr. Richard T. Gregg, Biologist, Division of Water Pollution Control, State of Louisiana, for their criticism and advice in preparing this manuscript.

REFERENCES

- Elkin, Harold F. 1956. Waste Disposal and Water Conservation. Presented at Stream Pollution and Waste Disposal Conference, Western Petroleum Refiners Association, Tulsa, Okla.
- Graves, Ben S. 1956. Sanitary Sewerage Treatment Plant at Shell Oil Company's Norco Refinery. Proceeding of the Fifth Annual Water Symposium, La. State University Engineering Experiment Station, Bull. No. 55.
- Graves, Ben S. 1958. Biological Oxidation of Phenols. Presented at a meeting of La. Petroleum Refiners Waste Control Council, January, 1959.
- Latiolais, Ray J. 1959. Sour Water Stripper. Presented at a meeting of La. Petroleum Refiners Control Council, March, 1959.

Toxicity Bioassay of Oil Refinery Effluents in Oklahoma

Troy C. Dorris, Wm. Gould, and
Chas. R. Jenkins

Zoology Department and Research Foundation
Oklahoma State University
Stillwater, Oklahoma

As part of its program for waste improvement, the Oklahoma Oil Refiners' Waste Control Council has supported a program of toxicity bioassay of refinery effluents since February 1957.

The testing program has been performed under a grant made by the Council to the Research Foundation and Zoology Department of Oklahoma State University. The grant provides for two graduate student research assistantships, faculty supervision, equipment, supplies, and travel. A trailer was equipped as a travel-

ing laboratory, and bioassays have been performed at each refinery with this trailer laboratory. In addition, bioassays were performed on samples sent to a laboratory on the campus of Oklahoma State University. This report is a summary of the information obtained from 42 series of bioassays from 14 separate refineries. Chemical analyses given in this report were performed by refinery personnel.

Toxicity bioassay was chosen as a means of evaluation of oil refinery effluents because of its potential relation to one of the principal provisions of most antipollution legislation--the prevention of injury to aquatic life. As discussed below, the principal pollutional characteristic of oil refinery effluents appears to be toxicity. It has been found in this study that treatment of effluents to reduce toxicity also results in improvement in other characteristics, including oil content, oxygen demand, chemical composition, turbidity, and odor.

METHODS

The early comprehensive discussion by Hart, et al, (1945) of methods to be followed in the toxicity bioassay and a later report by Doudoroff, et al, (1951) form the basis for procedures which were followed in the present study. The more recent paper by Turnbull, et al, (1954) presents a discussion of problems encountered in toxicity bioassay of petroleum refinery effluents. Henderson and Tarzwell (1957) have also discussed certain applications of the toxicity bioassay. The principles involved and details of test procedures are well covered in these papers.

The principal objectives of the present study were the investigation of the various methods of effluent treatment in use at the refineries and the analysis of the final effluent. In addition, tests were made on some process effluents to obtain information on their effect upon the final effluent. Bioassays were performed on more than 400 separate samples. Three test series were completed for each refinery. A maximum of 33 bioassays was performed in one test series at one refinery. An average of eight bioassays was performed in each testing period at each refinery, and approximately a week was occupied in completing each of these test series.

Fat-head minnows (*Pimephales promelas*) were used as test animals. These minnows

withstand handling and other laboratory conditions well. They appear to be moderately sensitive to refinery effluents, so that it is possible to measure effluents within a wide range of toxicity. Most of the minnows used were raised in ponds by University personnel.

The fat-head minnow is tolerant to low oxygen concentrations, and test solutions were considered to be satisfactory if they contained as much as 1 p.p.m. dissolved oxygen. Test solutions with low oxygen content or high oxygen demand were treated with pure oxygen, allowing a slow stream of small bubbles to come off a glass tube inserted into the test container.

During the early part of the program, water from receiving streams was used for dilution of test concentrations. Because of the great variability of these waters from time to time, it was felt that comparable data could be obtained only by the use of dilution water of uniform composition. Tap water from the Stillwater, Oklahoma, mains was used as a base, and chemical compounds were added to bring the dilution water up to about the upper limits for these compounds in United States surface waters (Hart, et al, 1945). The upper limit was chosen since the surface waters of Oklahoma generally are high in dissolved substances. The mean composition of the tap water and the synthetic dilution water is shown in Table 1. Duplicate tests were usually run with final effluents, using receiving stream water for dilution. In some cases, as when the receiving stream carried a heavy sewage load, the test samples with receiving stream dilution were more toxic.

THE MEDIAN TOLERANCE LIMIT

According to Turnbull, et al (1954), the recommended index of relative acute toxicity is the median tolerance limit (TL_m). It is defined as the concentration of test material at which just fifty per cent of the test animals survive for a specified period of exposure. In the present study, an exposure period of 48 hours was used (TL_m⁴⁸).

A median tolerance limit may be a concentration at which fifty per cent survival actually was observed in a test, provided higher and lower percentages have been recorded for the next lower and next higher test concentrations, respectively; or it may be a value derived by graphical interpolation. In the second case, it is based on observed percentages of test animals surviving at concentrations which were lethal to more than half and to less than half of the animals used as test subjects.

If a waste at its maximum test concentration exhibited no toxicity toward test animals after 48 hours' exposure, it was reported that the substance did not exhibit acute toxicity which was demonstrable and measurable by this test procedure, and is marked NT in the accompanying tables.

TOXICITY CHARACTERISTICS OF OIL REFINERY EFFLUENTS

Catalytic Cracker Effluents

Phenolic compounds are produced by decomposition of naphthenic acids in the catalytic cracking process. Caustic washes are used to

Table 1. Composition of Dilution Water

	Stillwater Tap Water	Synthetic Dilution Water	In 95 percent of the U. S., Surface Water is Less Than
Total dissolved solids p. p. m.	229	484	400
Bicarbonate (HCO ₃) p. p. m.	88.4	87.4	180
Sulfate (SO ₄) p. p. m.	13.4	105.5	90
Chloride (Cl) p. p. m.	70.9	188.8	170
Nitrate (NO ₃) p. p. m.	0.25	1.7	4.2
Calcium (Ca) p. p. m.	21.4	51.0	52
Magnesium (Mg) p. p. m.	21.1	28.5	14
Sodium & Potassium (Na&K) p. p. m.	8.3	95.3	85
Alkalinity M. O. p. p. m.	102.5	113.6	...
pH	7.5	7.9	8.3
Hardness p. p. m.	121.2	168.0	...

remove the phenols from the cracked gasolines, and the resulting extract is sold for reclamation. Steam is used in the fractionating towers to strip lighter components from the heavy residues. The condensed steam, known as "foul condensate", is collected in the overhead condenser. The condensate has a high phenol content, as well as high concentrations of sulfides and ammonia. This is the only process stream from which cyanide has been reported to us. The sulfides are more-or-less removed from the condensate by stripping in the foul condensate stripper. The effluent of the foul condensate stripper is one of the most toxic waste streams in the refinery. Table 2 shows the toxicity and the chemical characteristics as reported by refinery laboratories.

At one refinery, the foul condensate stripper was temporarily out of operation at one test period. The TL_{m48} at the oil separator was 2 percent, and the final effluent, after treatment in a series of ponds, had a TL_{m48} of less than 10 percent, as compared to a previous TL_{m48} of 38 percent with the stripper in operation.

At another refinery, the mean TL_{m48} of the final effluent with the catalytic cracker in operation was about 14 percent. During a period when the catalytic cracker was out of operation, the mean TL_{m48} was about 30 percent.

In two refineries an effort was made to dispose of this effluent by using it as make-up water for the crude desalter. This practice resulted in a considerable improvement of the

foul condensate stripper effluent, as shown in Table 3, which gives the percentage of change of each component.

Cooling Tower Blowdown

Table 4 shows the chemical analyses of cooling tower blowdown. Chromates, ammonia, and chlorine, as well as other compounds are used in treating cooling water for a variety of reasons. Chromates at concentrations as high as 24 p.p.m. in the blowdown are not toxic. Chlorine, in association with ammonia to form chloramines, is toxic at low concentrations.

Final Effluents

Table 5 shows the chemical analyses and toxicity characteristics of a number of final effluents. These data are from refineries where all of the effluents were gathered into a single outfall, and had not been subjected to any final treatment. In many cases the samples were taken out of the final oil separator, just before the effluent passed into a final treatment system.

The mean of the data may be taken to represent a fairly typical condition. The mean TL_{m48} is about 15 percent, with a rather narrow range of variation between about 3 percent and 22 percent. The mean pH is 9.1. The mean concentration of ammonia is about 22 p.p.m., of phenol about 7 p.p.m., and of sulfide 5 p.p.m. The mean chemical oxygen demand is about

Table 2. Toxicity and Chemical Characteristics of Effluents from Catalytic Crackers

TL_{m48}	pH	NH ₃ as N p. p. m.	Phenol p. p. m.	Sulfide p. p. m.	CN p. p. m.	COD p. p. m.
LT 1	8.3	250	86.7	0.0	2.4	4295
LT 1	9.1	200	43.0	22.4	2.6	677
1.8	9.5	400	20.5	12.8	0.85	1010
2.5	9.3	175	22.8	9.6	5.0	010
2.8	9.1	58.6	91.0	18.7	0.0	568
0.32	9.1	1000	56.5	54.4	2.3	458
2.2	9.6	99.8	26.8	23.7	...	917
5.6	9.3	224	10.6	52.0	...	524
Mean						
2.6	9.1	301	44.7	24.2	2.2	1185

Table 3. Percentage of Change of Toxicity and Chemical Components of Foul Condensate Water Stripper (Catalytic Cracker) Effluents by Passage Through Desalter

pH (decrease)	NH ₃ as N	phenol	sulfide	COD	IOD	TL _m ⁴⁸
0.6	63	78	87	51	...	250
1.0	30	87	69	72	...	1090
0.9*	21	47	0	...	71	338
0.5*	24	35	100	...	80	194
0.0	4	40	0	...	72	669
Mean						
...	28.4	57.4	51	61.5	74	508

Table 4. Toxicity and Chemical Characteristics of Cooling Tower Blow-Down

TL _m ²⁴	pH	Alkalinity		Hard- ness ppm	Cl as NaCl ppm	TDS ppm	COD ppm	DO ppm	Chrom- ate ppm	NH ₃ as N ppm	Chlor- ine ppm
		P ppm	MO ppm								
NT	7.5	0	230	502	980	...	...	4.7	24	...	...
NT	7.1	...	...	...	540	...	100	...	...	1.3	...
NT	8.4	20	164	630	3200	...	...	8.8	...	...	...
NT	7.2	0.0	34	1060	2130	...	...	11.0	24	...	...
LT32	6.8	0	12	445	170	1000	137	12.4	18.2	50	1.2
70	6.4	0	14	415	152	1120	163	15.6	29.4	60	0
68	7.1	0	22	370	66	656	21	14.4	25	0.1	0.75
90	6.3	0	11	255	66	708	59	13.0	18.9	1.0	0

Table 5. Toxicity and Chemical Characteristics of Untreated Final Effluents

TL _m ⁴⁸	pH	NH ₃ as N ppm	phenol ppm	sulfide ppm	sulfite ppm	COD ppm	IOD ppm	DO ppm	BOD ppm	OIL ppm	TDS ppm	Alkalinity	
												P ppm	MO ppm
21.5	8.7	21.4	4.2	0.3	...	...	3.4	...	...	...	...	...	...
21.5	8.7	17.8	4.0	0.3	...	...	0.0	...	...	...	...	...	...
21	8.5	30.0	1.7	17.0	...	379	...	0.0	102	86	4817	32	280
21	9.8	27.4	9.6	2.8	...	147	...	0.0	...	...	...	...	...
19	8.6	11.2	3.1	0.5	...	...	1.0	...	...	...	...	...	...
18.5	8.4	20.5	5.7	0.0	28.0	270	7.5	0.0	...	35	...	...	...
18	8.7	35.0	2.4	0.0	...	248	...	0.0	85	16	...	46	296
16.5	9.3	20.0	3.5	31.0	...	336	...	0.0	80	42	2575	66	270
15.5	9.2	40.0	2.8	0.0	32.0	4120	...	0.0	...	...	...	...	...
13	8.7	16.3	25.5	0.0	18.7	384	14.2	0.0	135	18	2322	88	194
12	8.7	1.0	0.1	4.0	...	...	27.5	0.0	...	...	1910	80	280
7.8	11.6	1.1	25.9	0.8	...	514	...	0.0	...	...	...	...	...
3.1	10.6	13.6	3.1	3.7	...	209	...	0.0	...	...	...	220	300
3.1	9.4	56.5	2.3	9.0	...	204	...	0.0	...	...	...	184	232
Mean													
15.1	9.1	22.3	6.7	5.0	26.2	299#	10.7	0.0	100	39	2900	102	264

*Increase

#Omitting highest value

300 p.p.m. The mean of a limited number of 5-day biochemical oxygen demand determinations is 100 p.p.m. There was no dissolved oxygen in any of the effluents. The mean dissolved solids concentration is about 2900 p.p.m. The mean oil content is about 40 p.p.m.

Table 6 shows the chemical characteristics of a number of final effluents which had been subjected to final treatment so that no toxicity was measurable by our test. The treatment consisted either of retention in ponds or of passage through a long, open ditch. The first two samples are a typical in that the effluents had been held in ponds for such a long time that a heavy algae growth, by photosynthetic activity, had raised the pH to a high level and had removed so much carbon dioxide that the alkalinity was greatly altered. However, maximum reduction of ammonia, phenol, and sulfide had occurred in these ponds. The data for these two ponds is not included in the means for this table.

It should be noted that these are observed values and give no indication of the maximum concentrations of the components which would produce a nontoxic waste.

The pH was reduced by two points to near-neutrality. The phenolphthalein alkalinity was removed, and total alkalinity was reduced by more than 50 percent. Ammonia was not sig-

nificantly reduced, but at the low pH undoubtedly existed as nontoxic salts. Phenols and sulfides were reduced about 90 percent. The chemical oxygen demand was reduced by about 50 percent and the biochemical oxygen demand was reduced about 80 percent. The dissolved oxygen content was increased to 4 p.p.m. in the treated effluent, as compared to no dissolved oxygen and an immediate oxygen demand of about 11 p.p.m. in the untreated effluents. The oily content was reduced about 80 percent. The dissolved solids content was unchanged.

IMPROVEMENT OF OIL REFINERY EFFLUENTS

Holding Ponds

At one refinery, a series of ponds with a design capacity of 60-days holding time was in operation (Table 7).

At all seasons there was a progressive decrease in ammonia, phenols, sulfides, and oil. Under winter conditions, ammonia and phenol were not removed as completely as other components.

Under cold-weather conditions (March 1958) there was a progressive decrease in pH and alkalinity. Under summer conditions, however,

Table 6 Chemical Characteristics of Final Effluents Which have been Rendered Nontoxic to Fat-Head Minnows by Treatment

pH	NH ₃ as N ppm	phenol ppm	sulfide ppm	sulfite ppm	COD ppm	DO ppm	BOD ppm	OIL ppm	TDS ppm	Alkalinity	
										P ppm	MO ppm
9.7	0.8	0.0	0.0	...	142	16.1	14	4	2166	30	80
9.3	1.0	0.0	0.0	...	126	10.2	20	2	2195	24	92
7.5	15.0	0.02	0.0	...	148	9.3	5	2	2073	0	112
7.5	15.0	2.0	1.0	5.0	196	4.0	36	...	3274	0	138
7.4	16.0	0.25	0.0	...	132	4.4	8	3	2161	0	120
7.3	16.3	0.4	2.6	3.6	230	5.0	35	7	3584	0	108
7.2	16.0	0.4	0.2	...	152	0.1	14	4	2193	0	124
7.0	11.7	0.5	0.0	4.7	142	2.0	30	10	4155	0	128
6.8	15.0	1.0	1.0	3.0	146	3.5	...	...	2774	0	124
Mean 7.2	15.0	0.65	0.7	4.1	164	4.0	21	5	2888	0	122

(Does not include first two samples. See discussion in text).

Table 7. Toxicity and Chemical Characteristics of Effluents Held in Ponds

a - August 1957, b - August 1958, c - March 1958

		Temp. °F	TL _m ³⁸	pH	Alkalinity		TDS ppm	NH ₃ as N ppm	phenols ppm	sulfides ppm	DO ppm	COD ppm	BOD ppm	OIL ppm
					P ppm	MO ppm								
Pond 2	a	92	18	8.7	46	296	...	35	2.4	0.0	0.0	248	85	16
	b	85	50	9.2	46	244	2008	19	2.5	7.1	0.0	268	45	22
	c	82	17	9.3	66	276	2575	20	3.5	31.0	0.0	336	80	42
Pond 3	a	81	38	8.9	28	210	...	16	1.2	0.0	0.0	209	52	...
	a	81	26	8.9	32	206	2113	19	1.2	22.0	0.0	210	53	10
	b	83	40	9.2	42	230	1961	17	1.1	3.7	0.0	225	33	14
	c	58	GT 32	9.3	64	230	2310	19	2.5	13.0	0.0	228	59	21
Pond 4	a	79	44	8.8	28	182	2101	18	0.2	10.0	0.0	195	42	11
	b	79	N. T.	8.5	2	160	1942	16	0.2	0.2	1.1	208	30	13
	c	55	GT 32	9.2	48	208	2299	19	1.0	0.8	0.0	212	43	9
Pond 5	a	78	56	7.7	0	180	2080	16	0.15	0.7	0.0	187	45	7
	a	78	65	8.1	0	106	2162	14	0.35	7.0	0.0	198	55	6
	b	79	N. T.	8.1	0	150	1923	13	0.07	0.0	0.0	186	21	13
	c	50	45	8.3	6	172	2284	18	0.5	0.5	0.0	188	30	5
Pond 6 3rd Bay	a	78	N. T.	9.0	24	110	2238	4.5	0.0	0.0	7.4	158	17	4
	b	80	N. T.	8.4	4	112	1936	4.0	0.025	0.0	4.3	163	15	5
	c	48	N. T.	7.2	0	124	2193	16	0.42	0.2	0.1	152	14	4
Pond 6 Outfall	a ¹	76	N. T.	9.3	24	92	2195	1.0	0.0	0.0	10.2	126	20	2
	b	80	N. T.	7.7	0	92	1990	3	0.025	0.0	0.6	158	11	3
	c	47	N. T.	7.4	0	120	2161	16	0.25	0.0	4.4	132	8	3
Pond 7 Outfall	a	...	...	...	...	...	...	...	...	...	...	...	...	...
	b	81	N. T.	8.1	0	76	2070	1.5	0.020	0.0	7.0	149	9	2
	c	47	N. T.	7.5	0	112	2073	15	0.023	0.0	9.3	148	5	2

there was a heavy growth of algae, mostly blue-greens of the genus *Chroococcus*, and in the latter part of the pond series, algal photosynthesis caused an increase in pH and alkalinity.

Passage of Effluents in Open Ditches

Passage of effluents in open ditches usually results in remarkable improvement within a short time. Information was obtained on the changes in the characteristics of four separate ditches.

At one refinery, the final effluent of about 2,500,000 gallons per day is held in a pond for about 2.7 days before being discharged to a ditch 3.7 miles long. Tests show that in dry weather, with no surface run-off, the effluents require 16-20 hours to complete the passage. The total fall in the 3.7 mile distance is 50 feet, with the major fall occurring in the last mile, so that the effluents spend the most time in the upper part of the ditch. Because of difficulty in reach-

ing the outfall to the river, most of the downstream samples were taken at a point 2.8 miles below the holding pond. Table 8 gives data on changes in TL_m⁴⁸ as well as chemical components. The tests of April 1958, were spaced in such a way as to attempt to sample a mass of effluent at the head of the ditch and after it had completed its passage at the end of the ditch, since there was a considerable daily variation in the composition of the effluent.

In one situation, refinery and municipal sewage plant effluents enter a small ditch. This ditch is about 7.5 miles long and apparently is an intermittent stream. The sewage effluent seems to have had little, if any, dilution effect, since the improvement of the refinery effluent at the sewage outfall is no greater than would be expected in a flow of equal distance anywhere else along the ditch.

Table 11 shows the progressive improvement of the effluent of a small refinery as it passed

¹No effluent, system still filling

Table 8. Changes in Toxicity and Chemical Characteristics of Effluents in an Open Ditch

	TL ⁴⁸ _m	pH	Parts per million									
			Alka- linity P MO	NH ₃ as N	phenols	sulfide	sulfite	Oil	COD	IOD	DO	
<u>April 1, 1958</u>												
Head of Ditch	LT49	8.6	14 164	14	2	0	9	...	300	0.0	0.8	
2.8 miles downstream	85	7.4	0 132	19	2	2	4	...	246	0.0	3.1	
<u>April 2, 1958</u>												
Head of Ditch	65	8.5	0 138	10	2	1	10	...	238	0.0	1.2	
2.8 miles downstream	100	6.8	0 124	15	1	1	3	...	146	0.0	3.5	
<u>July, 1957</u>												
Head of Ditch	35	8.6	34 154	23.2	9.1	5.5	14.8	13	244	0.4	0.0	
2.8 miles downstream	LT56	7.3	0 108	16.3	0.4	2.6	3.6	7	230	0.0	5.0	
<u>August, 1958</u>												
Head of Ditch	39	7.8	0 104	41.0	6.0	9.0	25.0	...	242	...	...	
1.8 miles	68	7.3	0 102	47.0	3.0	3.0	16.0	...	220	...	...	
2.8 miles	79	7.2	0 110	42.0	2.0	3.0	16.0	...	220	...	...	
3.7 miles	89	7.4	0 100	43.0	2.0	0.0	12.0	...	195	...	...	

Table 9. Changes in Toxicity of Effluents in an Open Ditch

	Miles Downstream	TL _m ⁴⁸			
		1/28/58	2/4/58	5/19/58	5/26/58
1. Outfall to ditch, upstream refinery	0	7.6	4.4	1.9	4.2
2. Above sewage outfall	1	LT10.0	16.5	10.0	9.0
3. Below sewage outfall	2	15.5	23.0	12.5	13.9
4. Outfall to ditch, downstream refinery	2.5	...	13.3	...	4.5
5. 1-1/4 mile below downstream refinery	3.75	...	24.0	...	24.0
6. 2-1/2 miles below downstream refinery	6.25	...	GT18.0	...	GT75
7. Ditch outfall at receiving stream	7.5	...	LT32.0	...	100

Table 10. Analysis of Dilution Water Used in Toxicity Bioassay, February, 1958

	Parts per million	
	Standard Water	Receiving Stream
Calcium (Ca)	64	103.5
Magnesium (Mg)	19.4	123.0
Sodium 2nd potassium (Na & K)	44.6	16.2
Bicarbonate (HCO_3)	61.1	87.3
Chloride (Cl)	139.0	243.0
Sulfate (SO_4)	86.0	370.0
Total dissolved solids	534.0	1223.0
Total alkalinity	159.1	220.9
Total hardness	144.0	610.0

down a small intermittent-type stream. During the February test a small amount of rainfall run-off was in the ditch. The effect of this dilution is strikingly shown at station 3b, where a small tributary stream raised the TL_{m48} from 24 percent to 48 percent. Otherwise, the improvement of the effluent in the ditch was probably largely the result of factors other than dilution. The data show that dissolved oxygen reached measurable levels while the stream was still quite toxic. Reduction of toxicity does not appear to be entirely dependent upon seasonal temperatures, but, instead, seems to be directly related to the initial level of toxicity of the effluent.

The test for February shows an interesting effect of the receiving stream. The TL_{m48} of the effluent at the end of the ditch, when tested with standard dilution water is 92 percent. When tested with receiving stream water, the TL_{m48} was 70. The above comparison (Table 10) of the standard water and the receiving stream water shows that the latter was much harder and more alkaline, suggesting a synergistic action between the effluent and the receiving stream.

Table 12 shows the effect of a passage of two miles for an effluent of about 2, 000, 000 gallons per day. A part of this effluent is held for several days in a large pond before being mixed with boiler blowdown and discharged to the ditch. Good improvement in TL_{m48} and pH are shown.

When effluents are passed through open ditches there is usually a marked reduction in pH, alkalinity, sulfites, immediate oxygen de-

mand, chemical oxygen demand, sulfides, and phenols. Dissolved oxygen concentrations are increased. Ammonia does not undergo any consistent changes as to total concentration, but undoubtedly is changed to the salt forms since the pH is lowered. The toxicity is usually greatly reduced. These changes appear to be independent of any dilution which may be available, but are augmented by dilution.

THE EFFECT OF OIL REFINERY EFFLUENTS ON STREAMS

It is commonly believed that the principal effect of refinery effluents is the depletion of oxygen in the receiving stream. Such an effect is frequently found in sewage wastes. Mau (1954) mentions, "the degrading effects of refinery wastes on streams, caused primarily by an oxygen deficiency". Coogan and Paille (1954) studied a Louisiana refinery in which the effluents were said to have been nontoxic when bioassayed. The authors concluded that the most important effect of the effluents was the high oxygen demand, which resulted in the de-oxygenation of the receiving stream. In this particular refinery, cooling was on a once-through basis, and cooling water provided high dilution. Volume of total plant effluent amounted to about 166, 000, 000 gallons per day. Ludzack, et al, (1957) reported that the principal effect of a refinery effluent in Ohio was the formation of beds of oily sludge which depleted oxygen when disturbed by high waters. It is not apparent that either Mau or Ludzack gave any consideration to the possible toxic effects of the effluents they studied.

Table 11. Changes in Toxicity and Chemical Characteristics of Effluents Passing Down an Intermittent Stream

Station	TL _m ⁴⁸			pH	°C	IOD	DO
	June	Oct.	Feb. (1)				
1. Refinery outfall	13	42(2)	23	8.7	33	16.8	...
2. 1000 feet downstream from refinery outfall. .	...	46	21	8.6	28	17.2	...
3a. One mile below station 2	...	GT56	24	8.2	18	15.0	...
3b. Same, after dilution by small tributary	...	...	42	...	...	...	...
4. About half-way between station 3 and 5	...	...	...	8.1	20	...	1.05
5. About 2 mi. below station 2	24	100	70	7.9	14	...	1.10
6a. Outfall to river, about 3.5 mi. below station 2 Standard dilution water	62	...	92	...	16	...	4.6
6b. Same as 6a, receiving stream dilution water	...	100	70	...	...	...	...

Table 12. Changes in Toxicity and Chemical Characteristics of Effluents Passing Down an Open Ditch

	TL ⁴⁸ _m	pH	Parts per million				
			Alkalinity		NH ₃ as N	phenol	sulfide
			P	MO			
March, 1958							
Head of ditch	13.5	9.4	96	220	...	0	0
2 miles downstream	100	7.2	0	144	...	0	0
August, 1957							
Head of ditch	22	8.7	95	300	...	3	...
2 miles downstream	80	8.0	15	225	...	3	...

(1) Chemical data apply only to February test.

(2) At the time of testing a deposit of asphalt was being burned off of a small pond just above the refinery outfall, and the TL_m⁴⁸ was unusually high.

Information obtained in the present study indicates that toxicity rather than oxygen demand is the most important effect of oil refinery effluents on receiving streams, at least in the situations faced by Oklahoma oil refiners. All untreated final effluents and most process effluents tested in this program have been found to be toxic, with median tolerance limits (TL_m 48) of about 15 percent (see Table 5). The only nontoxic process effluents found were those from cooling towers, and these were toxic if the towers had been treated with chlorine. Even with dilution from cooling tower blowdown, final effluents before treatment were always toxic. Several cases had been observed where immediate oxygen demand has been satisfied, with dissolved oxygen concentrations up to 4 or 5 ppm. and yet the effluents were still toxic (see Tables 9 and 11).

ACKNOWLEDGMENT

Various personnel of the Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, especially Dr. Clarence M. Tarzwell, have been of considerable assistance, and grateful acknowledgment is made of their help.

REFERENCES

- Coogan, F. J., and E. B. Paille. 1954. Physical and Chemical Characteristics of waste water discharges. *Ind. and Eng. Chem.*, 46(2):290-296.
- Doudoroff, P., Anderson, B. G., Burdick, G. E., Galtsoff, P. S., Hart, W. B., Patrick, R., Strong, E. R., Surber, E. W., and Van Horn, W. M. 1951. Bio-Assay Methods for the Evaluation of Acute Toxicity of Industrial Wastes to Fish. *Sew. and Ind. Wastes*, 23(11).
- Doudoroff, P., and Katz, M. 1950. Critical Review of the Literature on the Toxicity of Industrial Wastes and Their Components to Fish. I. Alkalies, Acids, and Inorganic Gases. *Sew. and Ind. Wastes*, 22(11).
- Hart, W. B., Doudoroff, P., and Greenbank, J. 1945. The Evaluation of the Toxicity of Industrial Wastes, Chemicals, and Other Substances to Fresh-Water Fishes. The Atlantic Refining Co., Philadelphia, Pennsylvania.
- Henderson, Croswell and Tarzwell, C. 1956. Bio-Assays for Control of Industrial Effluents. *Sew. and Ind. Wastes*, 29(9).
- Ludzack, F. J., Ingram, W. M., and Ettinger, M. B. 1957. Characteristics of a Stream Composed of Oil Refinery and Activated Sludge Effluents. *Sew. and Ind. Wastes*, 29(10).
- Mau, Gordon E. 1954. Pilot-Plant Studies of Refinery Wastes Treatment on Trickling Filters. *Sew. and Ind. Wastes*, 26(10).
- Turnbull, H., J. G. DeMann, and R. F. Weston. 1954. Toxicity of Various Refinery Materials to Fresh Water Fish. *Ind. and Eng. Chem.*, 46(2):324-333.